EASTERN SHASTA COUNTY
GROUND WATER STUDY

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

JUNE 1984

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Cover Photographs (clockwise from upper left): Pleistocene basalt outcrop near Manton, Triassic volcanic rocks at Dry Creek, Crook Spring near Shingletown.

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State of California The Resources Agency Department of Water Resources Northern District

FOREWORD

Rural development often takes place without enough consideration of its impacts on its surroundings. This is particularly true in the case of ground water; when it is pumped faster than it is naturally replenished, the resource shrinks. While lowering water surfaces in wells are usually noticed quickly, other results of a falling water table may be less obvious and may escape notice until after serious harm is already done. Such phenomena as shrinking springs and streams, with resulting damage to natural vegetation and to wildlife, are often in this category.

The Shasta County Board of Supervisors recognized a potential for trouble from development in the eastern county and approved a cooperative two-year study, to be done by the California Department of Water Resources and the Shasta County Water Agency. The study was to find and report areas of plentiful or limited ground water so that decision-makers would be better informed and developers better equipped to make appropriate plans.

This report presents the ground water hydrology and geology of selected areas and recommends conservation and management measures that local agencies can use to stretch their water supplies. It also suggests development densities that would be appropriate for each area, based on the area's estimated ground water resources.

This report is a major first step in giving proper consideration to ground water occurrence, availability, and development potential in eastern Shasta County.

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INTRODUCTION

In July 1982 the California Department of Water Resources (DWR) began a two-year study of the ground water hydrology, availability, and development potential in selected areas of Eastern Shasta County. The State of California and the Shasta County Water Agency provided funding under a cooperative agreement (Appendix A).

Purpose and Scope

DWR prepared this report to help Shasta County make land-use decisions for its General Plan that reflect the land's ability to provide reliable sources of water for its inhabitants. The report presents findings of the study and gives estimates of ground water availability and development potential for each area investigated.

The study was undertaken to provide information on the ground water resources and hydrogeology in the upland areas of Eastern Shasta County. It was done at reconnaissance level and in greater detail where possible. This report discusses surface and subsurface geology, ground water hydrology, and estimated ground water availability and development potential for each area of concern.

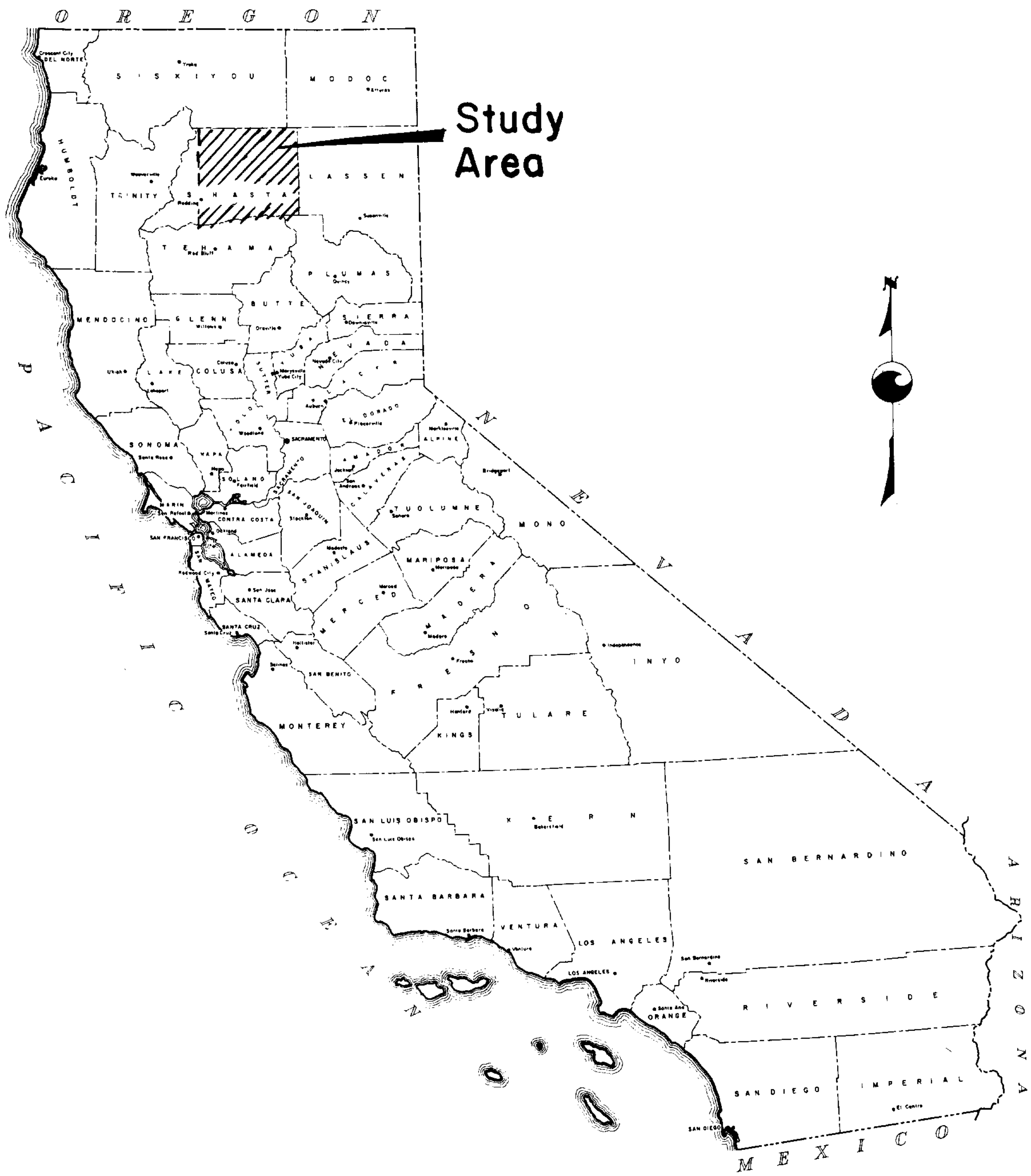
Area of Investigation

Location

Shasta County is in north central California, at the northern end of the Sacramento Valley (Figure 1). The investigated areas include the uplands or mountainous regions in the eastern and southeastern parts of the county. These areas (which correspond to the RA and RB land-use designations in the 1982 Shasta County General Plan[1/]) have been divided in Figure 2 into 13 units, based on geologic, hydrologic, and geographic parameters.

1/ RA: Rural Residential A, 2 acre minimum lot size.
RB: Rural Residential B, 5 to 10 acre minimum lot size.

Figure 1



Eastern Shasta County Ground Water Study

Location Map

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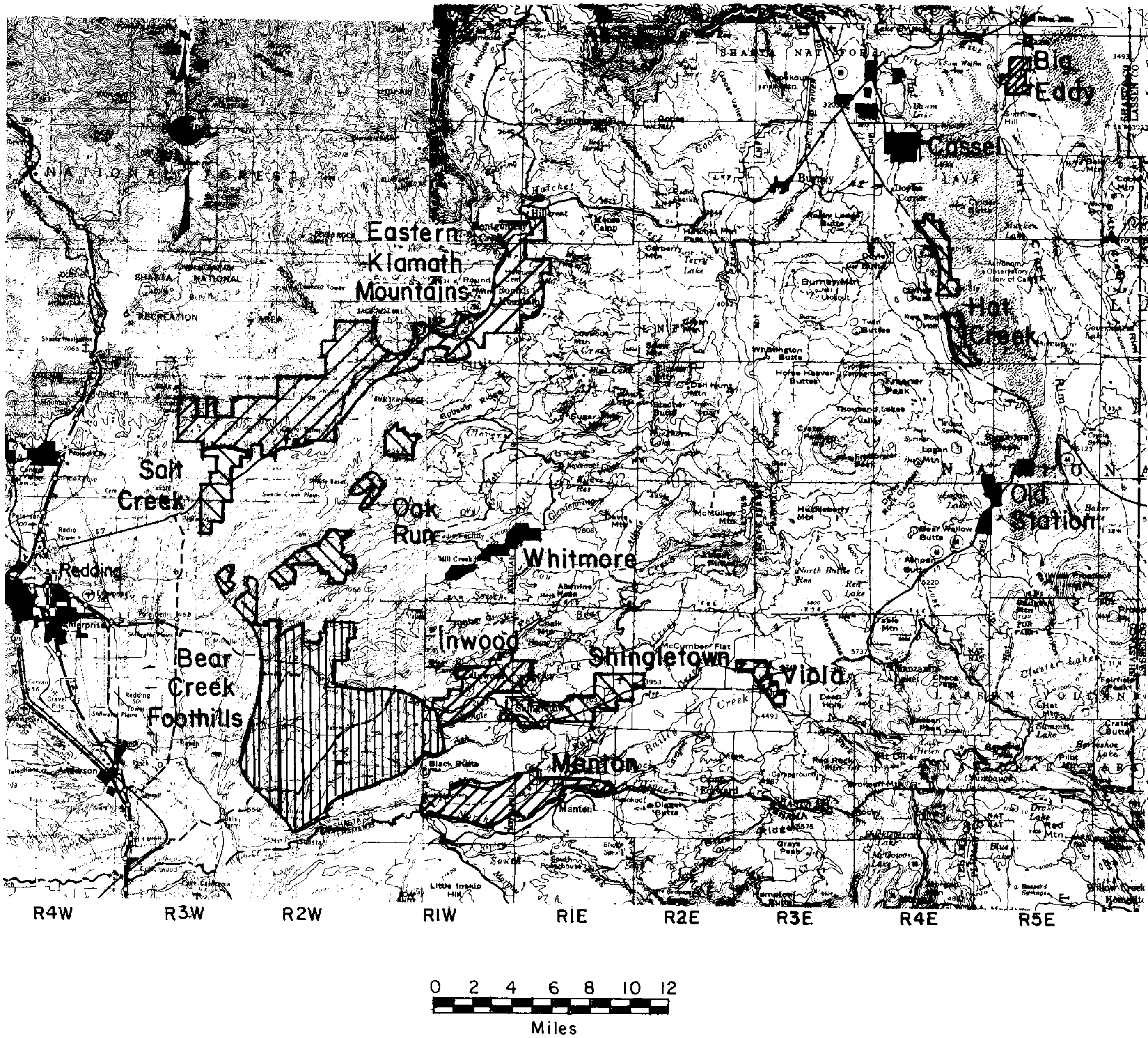
Figure 2



Eastern Shasta County Ground Water Study

Location Map of Areas Investigated

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Physiography

Parts of four of the eleven geomorphic provinces in California are found in eastern Shasta County (Figure 3). These are crossed by Highway 299 between Bella Vista and Fall River Mills in the following order, west to east: Great Valley, Klamath Mountains, Cascade Range, and Modoc Plateau.

Rocks of the Great Valley Province occur near Shingletown to north of Montgomery Creek and west to the Sacramento River and beyond. Areas underlain by these rocks are characterized by rolling hills of low relief or valley bottom lands where streams have eroded through overlying rocks of the Cascade Range. The Klamath Mountains Province rocks are exposed along Highway 299 from about six miles east of Bella Vista to Montgomery Creek and are cut by V-shaped stream valleys of moderate to high relief. The Cascade Range Province underlies most of eastern Shasta County and is a range of volcanic cones and basalt plateaus, rugged foothills, and deep stream-cut valleys. The Modoc Plateau is in northeastern Shasta County, generally east of Hat and Burney Creeks, and is characterized by northwest/southeast-trending basins bounded by steep cliffs or mountains of moderate to high relief.

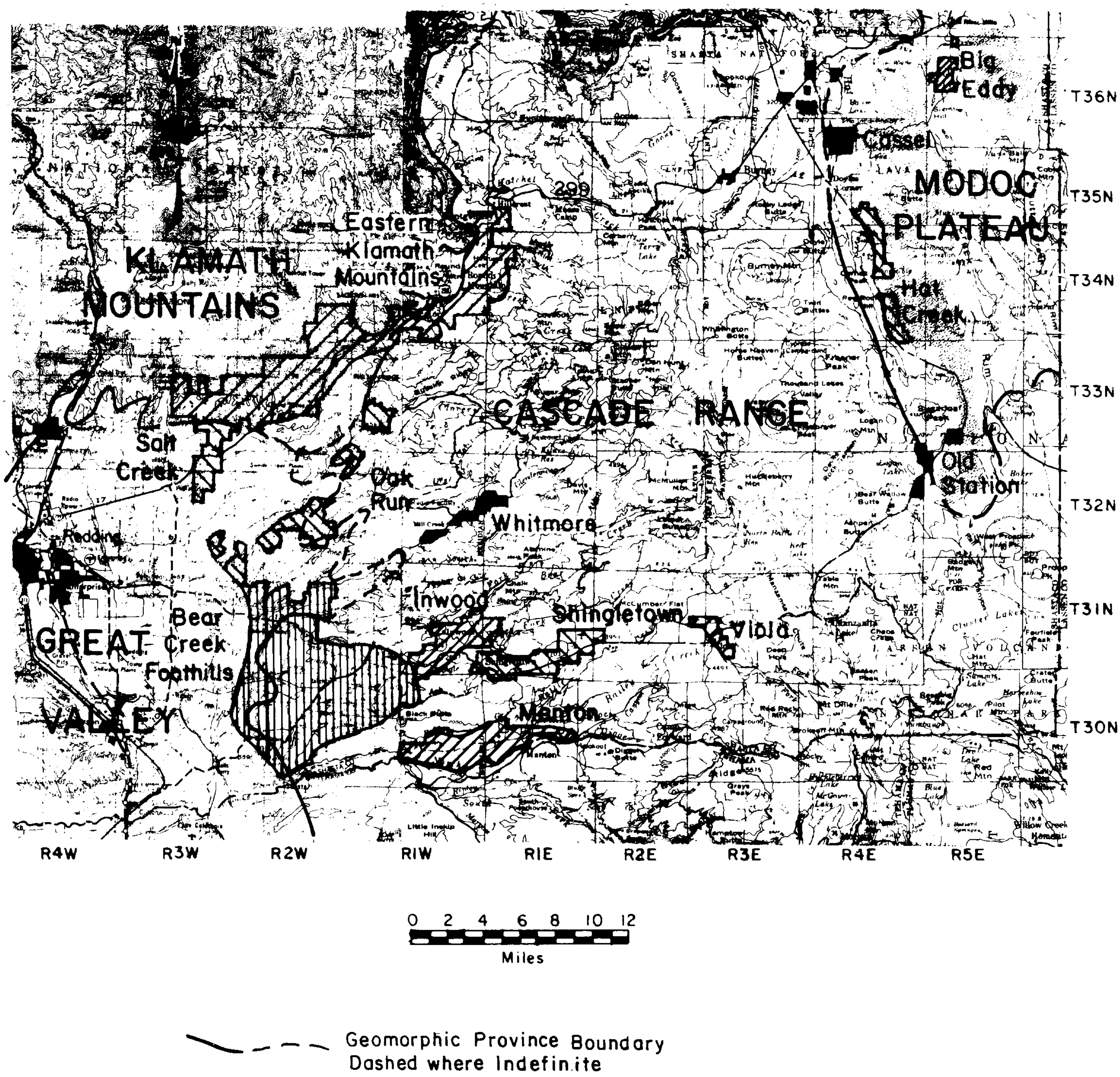
Climate

The climate is mild with moderate, wet winters and hot, dry summers. Eighty-five percent of the precipitation falls between November and April. Mean seasonal precipitation ranges from less than 20 inches at Fall River Mills to over 90 inches on the higher peaks of the Cascade Range crest (Figure 4). Above elevation 3,500 feet snowfall can be expected in winter.

Previous Investigations

The availability, occurrence, and character of ground water in Shasta County have been investigated mostly in connection with the Redding and Fall River Valley ground water basins. The uplands and mountainous areas of the county are usually mentioned as being underlain by rocks "considered to be largely nonwaterbearing" and dismissed from further discussion. However, in DWR Bulletin 74-8, "Water Well Standards--Shasta County" (1968), the mountainous areas are discussed in some detail, and in DWR Bulletin 22, "Shasta County Investigation" (1964), the Burney basin and Hat Creek Valley are given brief mention. Other investigations dealing with the geology of eastern Shasta County and ground water flow in fractured rock are listed in the bibliography.

Figure 3



Eastern Shasta County Ground Water Study

Geomorphic Provinces of Eastern Shasta County

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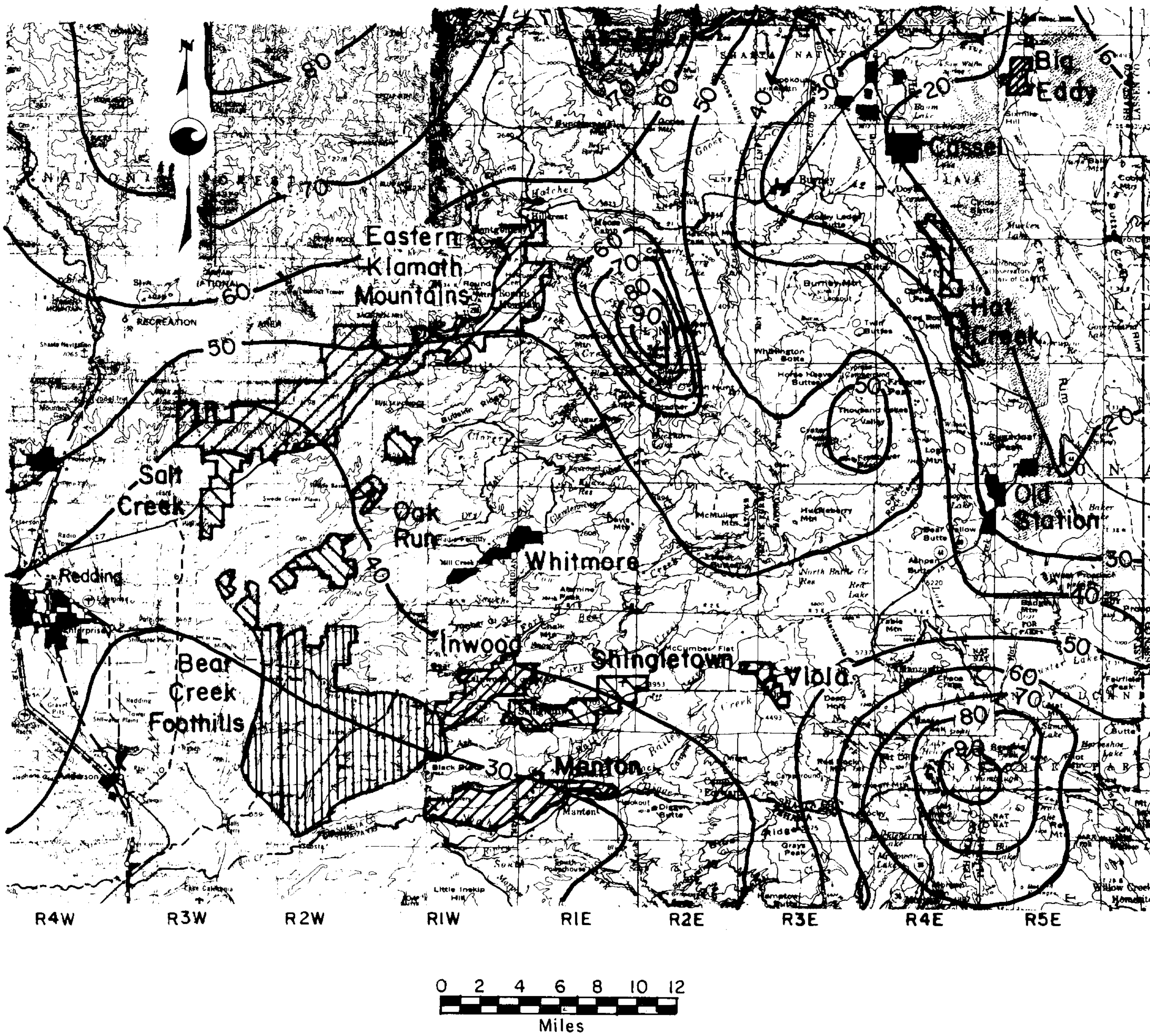
Figure 4



— 30 — Isohyetal Contour showing inches of precipitation.

SOURCE: USGS 1969

Eastern Shasta County Ground Water Study

Mean Annual Precipitation in Eastern Shasta County

1984

SUMMARY AND CONCLUSIONS

The Department of Water Resources started the Eastern Shasta Ground Water Study in August 1982 to provide a basis for sound land-use management decisions for the Shasta County general plan. The specific areas investigated are in eastern Shasta County that are not underlain by ground water basins, but instead generally overlie fractured rock. They are divided into thirteen separate units based on geologic, geographic, and hydrologic parameters.

One hundred twenty-five wells were field located and 69 of these were incorporated into a monthly water level monitoring grid. Data contained in an additional 459 well drillers reports were also evaluated.

The occurrence, availability, and development potential of the ground water resource in each unit were estimated. Ground water was found to occur in all units though its availability is questionable in some due to various reasons, i.e., depth to water is too great to economically develop; well yields are too meager or nil. These findings are reflected in the estimates of ground water development potential for each unit and summarized in Table 1.

Ground water recharge in the areas investigated varied in source (rainfall or streamflow) and amount, depending on the local geology, topography, soils, and vegetative cover. Areas investigated that lie east of the crest of the Cascade Range (Big Eddy, Cassel, Hat Creek, and Old Station units) are recharged mainly from percolation of streamflow. West of the crest, recharge is mainly from precipitation. During dry years, recharge from precipitation is estimated to amount to little or none while wet years provide the greatest amounts. Recharge from unconsumed irrigation water is locally significant, but because of the small amount of irrigated lands in the areas investigated, it fails to make a substantial overall impact.

The water-bearing characteristics of the various rock types in the areas investigated varied considerably. Generally, Pleistocene to Recent basalts showed the greatest permeability and porosity while sedimentary rocks of the Cretaceous Chico Formation showed the least. Also, some rock units, though highly fractured and thus exhibiting moderate porosity, were devoid of ground water due to their position above the local water table.

In many of the areas investigated, the local topography at a well site is a prime factor in the occurrence of ground water and yield of the well. Generally, higher-yielding wells with shallow depths to ground water are common in topographic lows or areas of low topographic relief--low-yielding wells and

TABLE 1

SUMMARY OF GROUND WATER DEVELOPMENT POTENTIAL

EASTERN SHASTA COUNTY

Unit	Ground Water Development Potential	Comment
Bear Creek Foothills	Moderate	Topographic relief influences depth and occurrence of ground water. Availability increases from east to west. Water quality is generally good; poor quality water may be found in the Chico Formation.
Big Eddy	Good	Confined ground water hydraulically connected to the Pit River. Faults may provide route for contaminants to reach ground water.
Cassel	Poor-to-Good	Faults appear to drain shallow aquifers. Shallow perched ground water susceptible to contamination from septic systems.
Eastern Klamath Mountains	Poor-to-Moderate	Great variability in well yields due to diversity of geologic formations and topographic relief. Water quality is generally good; poor quality water may be found in the Chico Formation.
Hat Creek	Good	Depth to ground water varies from 60 to over 300 feet depending on topography.
Inwood	Poor	Existing ground water resource meets current demands. Additional development may cause overdraft. Water quality is generally good; poor quality water may be found in the Chico Formation.
Manton	Moderate	Variable occurrence of ground water. Well log data are lacking for western 2/3 of unit. Water quality is good.

TABLE 1 (Continued)

Oak Run	Moderate	Aquifer characteristics and well yields vary due to various geologic formations. Availability generally increases from east to west. Water quality is generally good; poor quality water may be found in the Chico formation.
Old Station	Poor-to-Good	Depth to ground water excessive (>800') north of Big Springs fault. Abundant shallow ground water south the fault. Water quality is good.
Salt Creek	Poor	Most of the area underlain by impervious-to-semi-impervious rock. Confined ground water may be encountered at depth. Water quality is generally poor.
Shingletown	Moderate	Adaquate ground water for domestic uses. Depth to ground water increases and well yield decreases from east to west. Water quality is good.
Viola	Good	Shallow perched aquifer and deeper, very pervious aquifer, present. Water quality is good.
Whitmore	Poor-to-Moderate	Existing ground water resource appears adaquate for current density of development. There is currently insufficient data available to qualify the resource.

"dry holes" are common on hilltops and along ridge crests. This correlates to the presence of generally thicker soils and deeper weathering, and hence greater storage capacity, in the areas of low topography.

In some areas, the potential for future development should not be based solely on the availability of ground water, but on the potential for ground water impairment. A plentiful supply of ground water becomes useless if it becomes contaminated by the people who develop it.

The Cretaceous Chico Formation consists of interbedded shale, sandstone, and conglomerate of marine origin which may contain saline connate water. This formation, in part, underlies the Salt Creek, Eastern Klamath Mountains, Oak Run, Inwood, and Bear Creek Foothills units and can be a source of poor quality ground water.

RECOMMENDATIONS

The following recommendations concern the conservation and management of ground water in Shasta County. In most instances, these can be implemented within the existing administrative framework of the county.

Conservation Measures

It is estimated that the average annual per capita water consumption in Shasta County is about 0.1 to 0.2 acre feet per year (90 to 180 gallons per day). It may be possible to further reduce this demand by implementation of recommendations 1 and 2 below. Additionally, existing development could also contribute to water conservation efforts by incorporating these recommendations where feasible. Recommendations 3, 4, and 5 are designed to maximize ground water recharge while minimizing runoff.

1. All new development (single family, condominiums, subdivisions, etc.) should be required to incorporate proven water conservation technology in the planning and construction of the project. These should include, but not be limited to, low-flush toilets, flow-control inserts on showers, single-control faucets, water-efficient dishwashers and clothes washers, grey-water recycling, and hot-water pipe insulation.
2. Encourage the installation of efficient irrigation systems that minimize runoff and evaporation and maximize the amount of water that will reach the plant roots. Drip irrigation, soil moisture sensors and automatic irrigation systems are a few methods of increasing irrigation efficiency.
3. Encourage cluster development where feasible to reduce the amount of land being converted to urban use. This will reduce the amount of impervious ground cover and aid in ground water recharge.
4. Wherever possible, all new development should keep rainwater on site in a retention basin to aid in ground water recharge. Where this is not feasible, the development should be designed to reduce, retard, and disperse runoff. This may be accomplished by mulched and/or terraced slopes to reduce erosion and retain rainfall, porous drain swales and paving materials for infiltration, outsloped roads to spread runoff evenly down slope, and landscaping with suitable water-conserving erosion control plants that will protect the soil, facilitate infiltration of rainwater, and reduce runoff.

5. Preserve existing natural drainage areas such as swales, dry washes, etc.--and encourage the incorporation of them in new developments, rather than covering them over, filling them in or otherwise destroying them. This would aid in ground water recharge.

Management Measures

It is recommended that the Shasta County Board of Supervisors modify existing ordinances to require a project developer to conduct a comprehensive hydrogeologic study and ground water supply evaluation for all proposed developments in the selected areas of Eastern Shasta County recommended for such studies in Table 2.

The study should address the following:

1. The amount of ground water available on an annual basis for supply, compared to the projected requirement.
2. Whether individual domestic or community wells are preferable.
3. Impacts of ground water development on other existing springs, wells, vegetation, and streamflow.
4. Chemical quality of the ground water.
5. Change in well yields after prolonged pumping (i.e., 3 to 10 days).
6. Determination of aquifer characteristics and boundries, recharge and discharge.
7. The impacts of waste disposal on ground water quality including sewage effluent, septic tank effluent, and suburban storm runoff.

The study area should include the project area and existing developments on property near the project.

Before a project developer begins a hydrogeologic study and ground water supply evaluation, the project developer should meet with the County's staff or consultants and discuss the scope of the study.

To determine well yields after prolonged pumping, aquifer characteristics and boundaries, and recharge and discharge, the following requirements for pump testing should be observed:

1. All test wells which are used to indicate quantities of water available should be constructed in accordance with the State of California Department of Water Resources Bulletin 74-8 entitled "Water Well Standards, Shasta County", dated August 1968.
2. The time of the year for testing should be during the latter half of the summer.

3. The capacity of the test pump at the selected lift should exceed the production capacity of the well. A control value on the discharge line should be provided to allow flow control.
4. Access down the well should be provided for an electric sounder in order to allow water level measurements.
5. Continuously recording flowmeters should be installed in the discharge line to provide exact measurement of discharge.
6. Water pumped from the well should be piped a sufficient distance away from the pumped well and observation wells so as not to influence the test results.
7. Test well locations should be specified by the County's staff or consultant in consultation with the project developer.
8. For individual domestic wells, the duration of pump test should be at least 72 hours; community wells shall be pumped for at least 10 days.

Regarding waste disposal, in addition to the requirements of "Shasta County Sewage Disposal Standards":

1. Detailed geologic mapping of the project area should be undertaken and show locations of boring and/or pits, areas of hard rock outcrops, shallow hard rock, shallow ground water, and any other data pertinent to the investigation.
3. The study should be performed by an engineering geologist certified in California.

In the final report, all data generated in the investigation, whether used to substantiate the findings or not, should be submitted in the report. For pump tests, these include: well yields, volume of water pumped, times of water level measurements, depth to water, water temperature, electrical conductivity, any other chemical analyses, and well logs and construction information of the pumped wells and any observation wells.

It is recommended that the County enlist the services of an engineering geologist certified by the State of California or contract with an agency with the appropriate expertise, to review and comment on hydrogeologic reports submitted by project proponents.

A long term ground water level monitoring program should be initiated to evaluate the effect of climatic variation on water levels, to provide a data base for future investigations, to provide data that may be used to anticipate local ground water shortages, and to evaluate the impact of future development.

Land Use Designation

The ground water development potential ratings in Table 1 are qualitative, based on existing well data, previous studies, and field observations. However, land use designations, as presented in the Shasta County General Plan, can be recommended for each unit where parcels will rely on individual wells, based on existing hydrogeologic knowledge. The recommended land use designations in Table 2 reflect this knowledge. These may be modified as more ground water data and its interpretation becomes available to provide a better understanding of the hydrogeology in eastern Shasta County, or, if other sources of water (i.e., surface water, community wells, water districts) are used.

TABLE 2

RECOMMENDED LAND USE DESIGNATIONS FOR
EASTERN SHASTA COUNTY GROUND WATER STUDY UNITS

Unit	Recommended Land Use Designation[1/]
Bear Creek Foothills	RB[2/] for lands above the 1000 foot elevation, RA for lands below.
Big Eddy	RB[2/]
Cassel	RA in section 5, 6, 8, and 17, T35N R4E, RB[2/] in remainder of unit.
Eastern Klamath Mountains	RB[3/]
Hat Creek	RB[2/]
Inwood	RB[3/]
Manton	RB[2/]

TABLE 2 (Continued)

Unit	Recommended Land Use Designation1/
Oak Run	RB2/ for lands above the 700 foot elevation, RA for lands below.
Old Station	RA south of Big Springs Fault, RB3/ north of the fault.
Salt Creek	RB3/
Shingletown	RB2/
Viola	RA
Whitmore	RB3/

1/ RA: Rural Residential A -- one dwelling unit per 2 acres

RB: Rural Residential B -- one dwelling unit per 5 acres if within one mile of a paved road; otherwise the density may not exceed one dwelling unit per 10 acres

NOTE: Recommended density based only on ground water development potential, other considerations may require lower densities

2/ Projects with proposed lot sizes less then provided for in the RB land use designation should require a hydrogeologic study and ground water supply evaluation before approval.

3/ A hydrogeologic study and ground water supply evaluation should be conducted prior to approval.

GEOLOGY

Geologic Setting

The areas investigated for this study lie mainly within the Cascade Range and Modoc Plateau Geomorphic Provinces and, to a lesser degree, within parts of the Klamath Mountains and Great Valley Geomorphic Provinces (Figure 3).

Cascade Range Province

The Cascade Range is an accumulation of volcanic flows, pyroclastic rocks, and associated plugs and sedimentary rocks. Rocks of this province underlie most of eastern Shasta County and, near Highway 299E and the Sacramento River, lap onto and partially cover older rocks of the Klamath Mountain and Great Valley Provinces. In composition, rocks of the Cascade Range Province are predominantly pyroxene andesite, but range from olivine basalt to dacite.

The Tuscan Formation is the most widespread unit of the Cascade Range within the areas investigated. Exposed continuously along the northeast side of the Sacramento Valley, it consists largely of breccias formed by volcanic mudflows, with individual beds 10 to 100 feet thick; the entire accumulation averages about 1,000 feet, with a maximum thickness of about 1,500 feet, observed along Mill Creek Canyon southwest of Mount Lassen (CDMG, 1966).

Andesitic, dacitic, and basaltic volcanic breccias, tuff breccia and interbedded lava flows, sandstone, conglomerate, and tuff are the principal rock types. Toward its western edge, volcanic conglomerate, sandstone and tuff appear, and still farther west it interfingers, at least in part, with the Plio-Pleistocene Tehama Formation of the Great Valley Province.

Capping the Tuscan Formation are Pleistocene to Recent alluvium and volcanic debris and basaltic, andesitic, and rhyolitic pyroclastic flows. The most extensive flow is west of Lassen Peak, covering more than 300 square miles. Other notable Quaternary volcanic flows are in the upper Cow Creek watershed and north, west, and south of Burney Mountain.

Modoc Plateau Province

The boundary between the Modoc Plateau and Cascade Range in northern California is indefinite. Block-faulting, characteristic of the Modoc region, extends into the Cascade Range and rocks characteristic of the two provinces intermingle (CDMG, 1966). The two main distinguishing features of the Modoc Plateau are the dominance of Recent volcanism and the very large number of northwest-to-north trending normal faults, some with displacements of more than 1,000 feet.

Rocks of the Modoc Plateau range in age from Miocene to Recent and, like the Cascades, are an accumulation of volcanic flows, pyroclastic rocks, and associated plugs and sedimentary rocks. In composition the volcanic rocks are predominantly basalt, but range from olivine basalt to andesite. Sedimentary rocks include claystone, sandstone, conglomerate, and diatomite.

Great Valley Province

The Great Valley is a large elongate structural trough that has been filled with a thick sequence of sedimentary rocks ranging in age from Jurassic to Recent. The Great Valley is about 450 miles long, reaching from just north of Redding to south of Bakersfield. In eastern Shasta County, Great Valley rocks are exposed in the Cow, Bear, and Ash Creek watersheds as far east as Shingletown, Whitmore, and Round Mountain. Near Montgomery Creek, Great Valley rocks are exposed in a few small tributaries to the Pit River.

The oldest Great Valley rocks in eastern Shasta County are the Upper Cretaceous Chico Formation. This unconformably overlies the older Mesozoic and Paleozoic rocks of the Klamath Mountains and in turn is unconformably overlain by the Eocene Montgomery Creek Formation and Tertiary rocks of the Cascade Range. Shale, sandstone, and minor beds and lenses of conglomerate comprise the Chico Formation.

Continental deposits of the Montgomery Creek Formation are intermittently exposed from near Round Mountain to the Shingletown area. The formation consists of loosely consolidated sandstone and shale near Shingletown and grades northward into moderately consolidated conglomerate, coarse sandstone, and shale.

East and south of Millville, erosion of the Cascade Range has yielded a thin unit of coarse Pleistocene volcanic gravel. It becomes more widespread to the southwest and is correlative to the Red Bluff Formation.

Klamath Mountains Province

Irwin (1966) divided the Klamath Mountains into four major belts. From west to east, they are the western Jurassic belt, the western Paleozoic and Triassic belt, the central metamorphic belt, and the eastern Klamath belt. Granitic and ultrabasic rocks occur in parts of all these belts. The eastern Klamath belt is the only unit of the province exposed in the study area. It consists of interbedded metasedimentary and metavolcanic rocks ranging in age from Middle Devonian to Middle Jurassic. The belt contains the Copley Formation, Dekkas andesite, Pit Formation, Bully Hill rhyolite, Hosselkus limestone, and the Brock shale and Modin Formation.

General Hydrologic Properties of Aquifers

Ground water occupies voids below the land surface in the zone of saturation. It chief sources are precipitation and streamflow. The amount of precipitation falling on a given area that percolates into the subsurface to become ground water depends on the area's characteristics; ground slope, soil, vegetative cover, and the permeability and porosity of underlying rocks. Some of the precipitation is returned to the atmosphere by plants and by evaporation in a process called evapotranspiration (ET). The rest becomes surface runoff.

Porosity is the ratio of the volume of voids (interstices) in soil or rock to the volume of its mass. It is an index of water storage when the material is saturated. Most rocks forming the earth's surface have void spaces that may contain water. These range in size from minute pores in clays to large lava tubes in basalt flows. Porosity is classified as being either primary or secondary. Primary porosity is created by the geologic processes that govern the origin of the geologic formation and is found in sedimentary and igneous rocks. Secondary porosity develops after the rock is formed; examples include joints, fractures, solution openings, and openings formed by plants and animals (Todd, 1980).

Permeability is the ability of the material to allow fluids to move through it. The degree of permeability depends on the size and shape of the pore space and the extent, size, and shape of the interconnections between pores. It is not necessarily directly related to porosity. Porosity may be high, but if the voids are small or not interconnected, the permeability is low.

An aquifer is a geologic unit that stores, transmits, and yields significant quantities of water to wells and springs. There are two general types of aquifers. In an unconfined aquifer, the "water table" is defined by the level at which water stands in a well that penetrates the water body. A confined aquifer is a completely saturated aquifer whose upper and lower boundaries are impervious or semi-impervious materials. Water rises above the upper boundary of the aquifer in wells that penetrate it. The potentiometric surface is the surface to which confined water will rise in a well. A well penetrating a confined aquifer is an artesian well, and if the pressure is great enough to cause the water to rise above ground surface, it is a flowing artesian well.

Transmissivity defines the rate at which water is transmitted through the width of an aquifer. It is expressed as gallons per day per foot width (gpd/ft) of an aquifer under a 100 percent hydraulic gradient.

Hydraulic gradient is the slope of the potentiometric surface or water table. It is defined as the change of pressure head per unit of distance of flow in a given direction. Ground water moves from areas of recharge to areas of discharge, or from areas of higher water level to areas of lower water level. The rate of ground water movement is normally very slow, in the magnitude of a few feet to a few hundred feet per year.

The static water level and pumping level are the two water levels before and after turning on a well pump; the difference in these levels is called drawdown. Specific capacity is the rate of discharge of a water well divided by the drawdown and is commonly expressed in gallons per minute per foot of drawdown (gpm/ft). Pumping a well in an unconfined aquifer locally depresses the water table and results in the formation of a cone of depression that defines the area of influence of the pumping well. A change in water level in a confined aquifer results in pressure changes in the surrounding aquifer material.

Water level changes not related to pumping in either confined or unconfined aquifers are due to annual and seasonal variations in the rate of recharge and discharge. Minor fluctuations may be due to changing atmospheric pressure, earthquake activity, and even the passage of trains!

The hydrologic cycle is the natural circulation of water through evaporation, precipitation, runoff, infiltration, transpiration, percolation, and seepage. Within any hydrologic system, the inflow of water will equal the outflow of water plus or minus any change in storage.

Hydrogeology of Fractured Rocks

Unlike many ground water basins in California where the aquifers consist of friable sedimentary rocks with primary porosities ranging from about 5 percent to 50 percent, the primary porosity of nonbasin, consolidated rocks, is generally low, ranging from almost nothing to a few percent. This investigation deals with generally nonbasin, hard-rock terrains. In these areas ground water availability, quality, and movement are for the most part dependent on the occurrence of fractures, or "secondary porosity", which constitute the flow channels for ground water movement.

Joints, Fissures, and Faults

Joint, fissure and fault are terms used to describe breaks and partings in otherwise consolidated rocks. In the broadest sense, a fracture is any break in a rock, regardless of its size or cause; a fissure is the space created by the parting of a fracture. Faults are fractures where adjoining rock masses have moved in relation to each other.

A joint is a surface of fracture with our displacement and without any relative movement parallel to the plane of the joint. They occur as a result of stress applied to the rock mass. Depending on the origin of the force, various modifiers are used to describe joints. Tectonic joints result from forces placed on rocks during orogenic events and can be further categorized as shear joints, which are closed, and tension joints, which tend to remain open. Exfoliation joints occur near the land surface and result from weathering and biological activities. Sheet joints form in rocks as a result of removal of rock load (pressure relief). These fractures tent to run parallel to the ground surface. Columnar or cooling joints occur in volcanic rocks due to shrinkage of the rock as it cools. These fractures tend to be perpendicular to the ground surface.

Fracturing tends to be greater in geologically older rocks that have been affected by several orogenies, but water-holding capacity (secondary porosity) can diminish with time as fractures fill with mineral deposits.

The depth to which fractures extend depends on their origin. Faults may be very deep, extending for miles below the surface of the earth. Joints, on the other hand, may extend only a few feet to a few hundred feet.

Hydrologic Aspects of Joints and Faults

In consolidated rocks, joints compose a 3-dimensional network of channels that extends tens-to-hundreds of feet below the ground surface, and when saturated, store and transmit water. Their ability to store and transmit water depends on the size of the opening, or fissure. Generally, joints tend to "close up" with depth, decreasing significantly their ability to store and transmit water. Hence the chance of getting a larger supply of water by drilling a well deeper becomes poorer.

Fault zones may be separated into three general hydrogeologic categories: those which readily transmit ground water, those which act as ground water barriers, and those which do neither.

When brittle, massive, or lithified rocks are faulted, many fractures may develop along the plane of movement. This zone of fracturing varies in width and density of individual fractures, and may contain little or no fault gouge[1/]. Such fault zones will readily transmit ground water. Most faults in the Modoc Plateau Geomorphic Province are believed to belong to this group.

Faults acting as ground water barriers are found within sedimentary deposits and certain water-yielding volcanic rocks. The barrier is formed by the offset of permeable beds against less permeable beds, or by formation of fault gouge in the fault zone that disrupt the continuity of water-yielding materials. Such ground water barriers may not completely stop the flow of water but merely impede it. Faults in the Cascade, Great Valley, and Klamath Mountain Geomorphic Provinces and in the Modoc Plateau, where they extend into sedimentary deposits may fall into this group.

No hydrologic effect occurs when fault gouge forms in already impervious rock, or no barrier develops as the result of the offset in pervious materials. Faults of this type may occur anywhere.

1/ Crushed and ground rock material filling or partly filling a fault zone.

HYDROGEOLOGY

Bear Creek Foothills Unit

The Bear Creek Foothills unit is the largest unit investigated in this study, comprising almost 64 square mile (41,000 acres). It reaches from east of Millville, south to Battle Creek and from the area northeast of Black Butte west to the edge of the Redding ground water basin (Figures 5 and 5a). The area varies in elevation from about 500 feet in the west to over 2,300 feet near Black Butte. The topography is generally gentle except where streams have cut deep canyons. Grasslands and stands of digger pine, oak, and brush are the typical vegetative cover. The area is only sparsely populated.

Local Geology

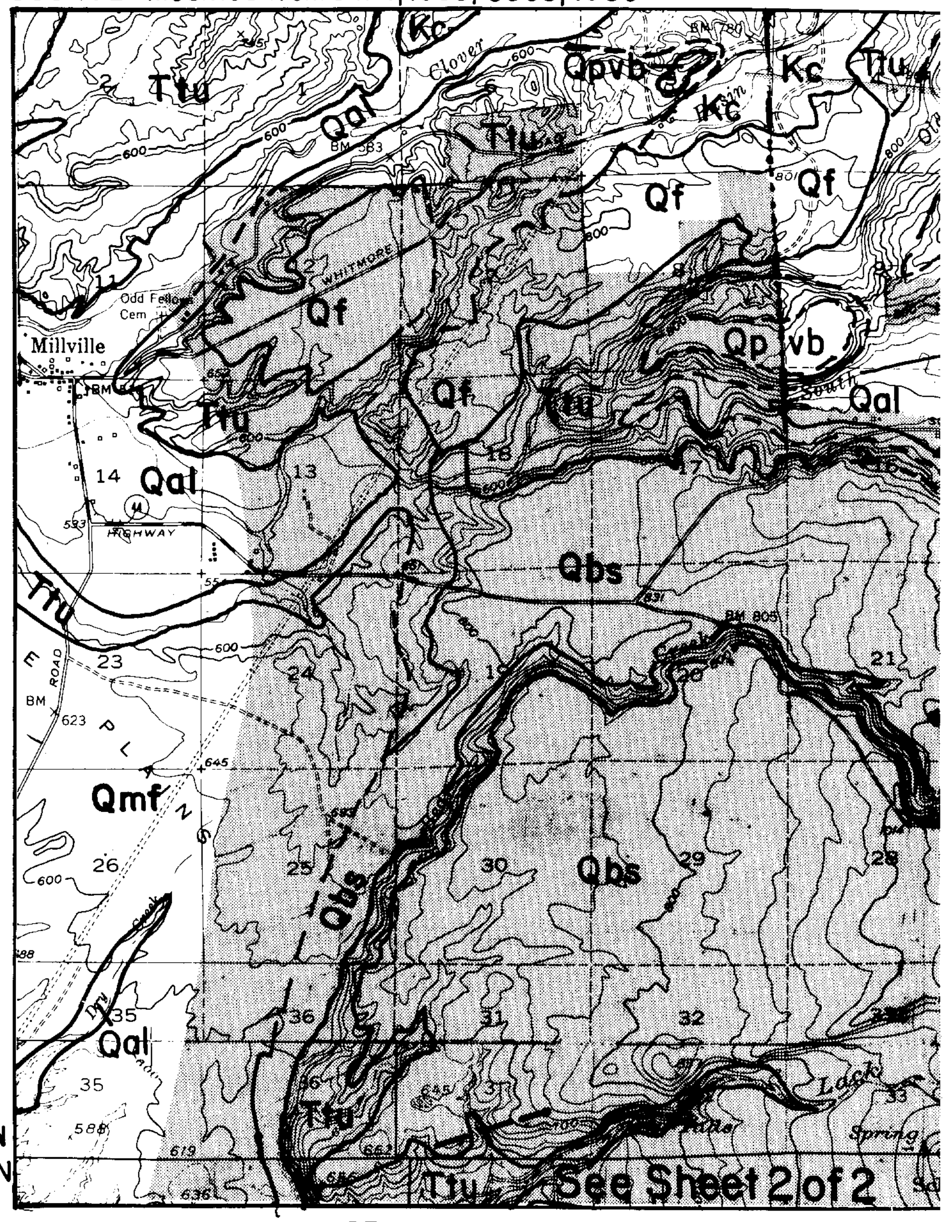
The Bear Creek Foothills unit lies at the lower elevations of the western flank of the Cascade Range and is underlain mainly by Tertiary and Quaternary volcanic and related sedimentary rocks. The Cretaceous Chico Formation, which unconformably underlies these, is exposed in valley bottoms where stream erosion has cut down through the overlying volcanic rocks.

The Chico Formation consists of shale, sandstone, and beds and lenses of conglomerate. It is exposed mainly in the northern part of the unit, in the South Cow, Old Cow, and Clover Creek drainages. Near Black Butte, according to well drillers' reports, it is found in the subsurface, usually at 200 to 400 feet, depending on the topography at the well site, i.e. the depth to the Chico Formation is generally greater under ridges than under valleys. Throughout the rest of the unit, it lies 400 to 800 feet or more below the cover of the younger volcanic and sedimentary rocks (DWR, 1968).

Unconformably overlying the Chico Formation is the Tuscan Formation, which is widespread throughout the area. It consists of tuff breccia, tuff, lava flows, and semiconsolidated clay, sand, and gravel. In the northern and eastern parts of the unit the Tuscan's thickness ranges from less than a foot at its contact with the Chico Formation to 200 to 300 feet under the uplands. Westward it thickens to 800 feet or more.

The Tuscan Formation changes in an east-west direction: tuff breccia and lava which dominate the eastern half of the unit, give way to tuff, tuffaceous clay, snadstone, and conglomerate in the west.

SOURCE: Modified from DWR, 1958; USGS, 1980



EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qf	Pleistocene Alluvial Fan Deposits
Qbs	Basalt of Shingletown Ridge
Qmf	Alluvial Fan of Millville Plain
Qpvb	Pleistocene Basalt

TERTIARY

Ttu	Tuscan Formation
Kc	Cretaceous Chico Formation

CONTACT
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FAULT
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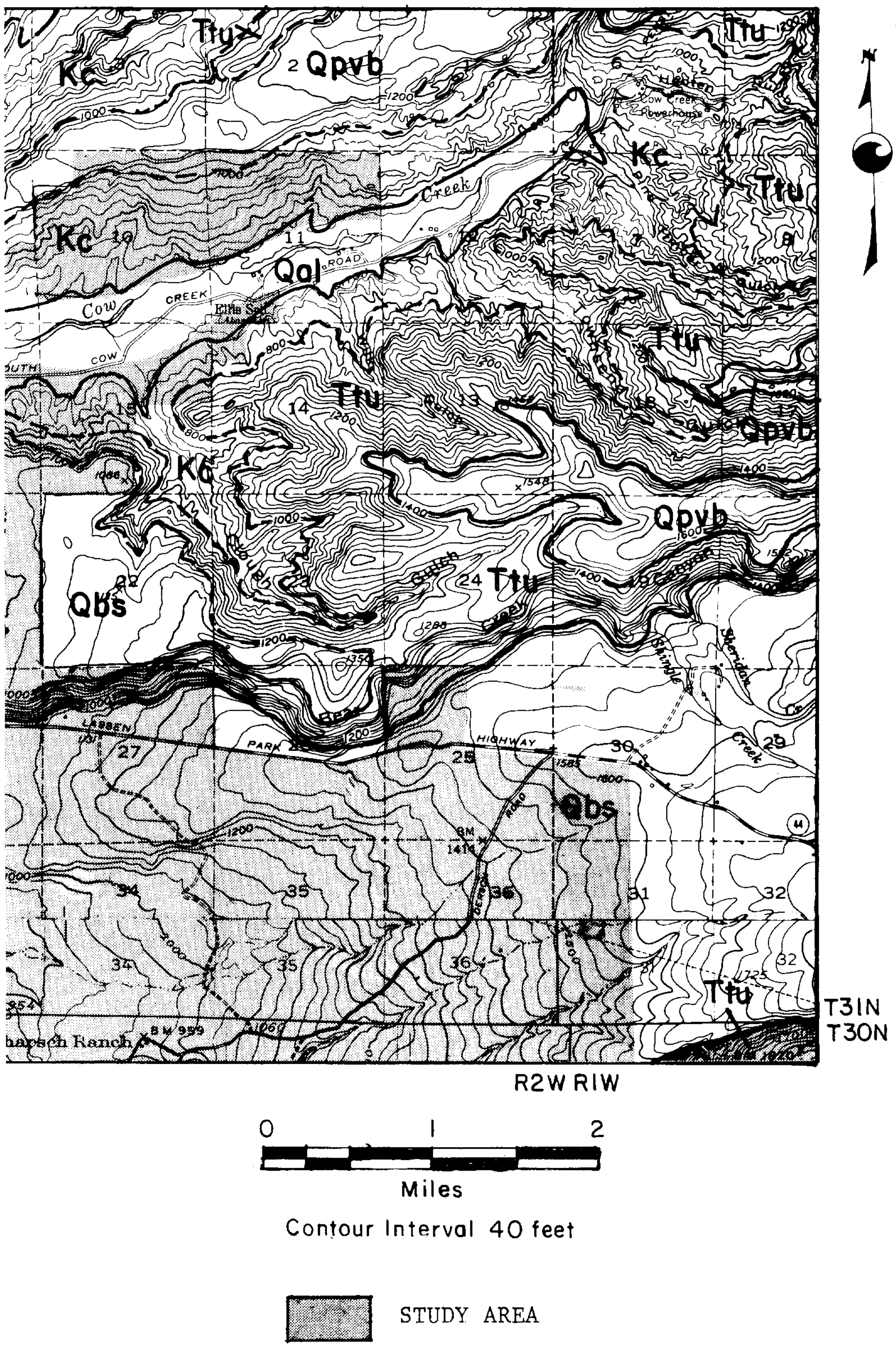
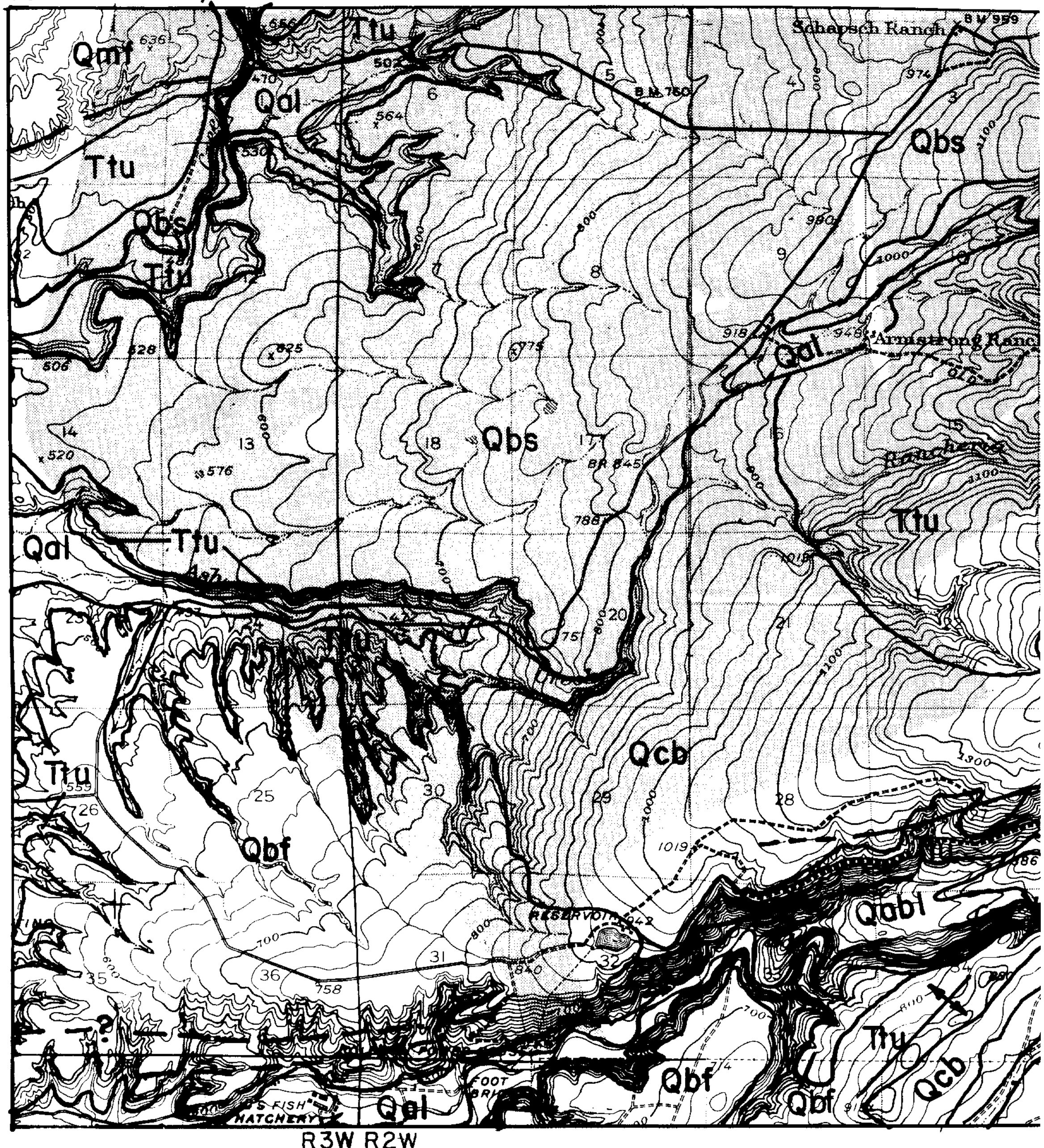


Areal Geology, Bear Creek Foothills Unit
Sheet 1 of 2 Sheets

SOURCE: USGS, 1980



EXPLANATION

QUATERNARY

Qal	Quaternary to Recent Alluvial Deposits
Qbbc	Basaltic Cinder Cone Deposits of Black Butte
Qbba	Ash of Black Butte
Qbb	Basalt of Black Butte
Qbs	Basalt of Shingletown Ridge
Qabu	Upper Hypersthene Andesite
Oam	Ash of Mount Maidu
Qabl	Lower Hypersthene Andesite
Qbf	Alluvial Fan Deposits of Battle Creek
Qmf	Alluvial Fan Deposits of Millville Plain
Qcb	Basalt of Coleman Forebay

TERTIARY

Ttu	Tuscan Formation
Tmc	Montgomery Creek Formation

CONTACT
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FAULT
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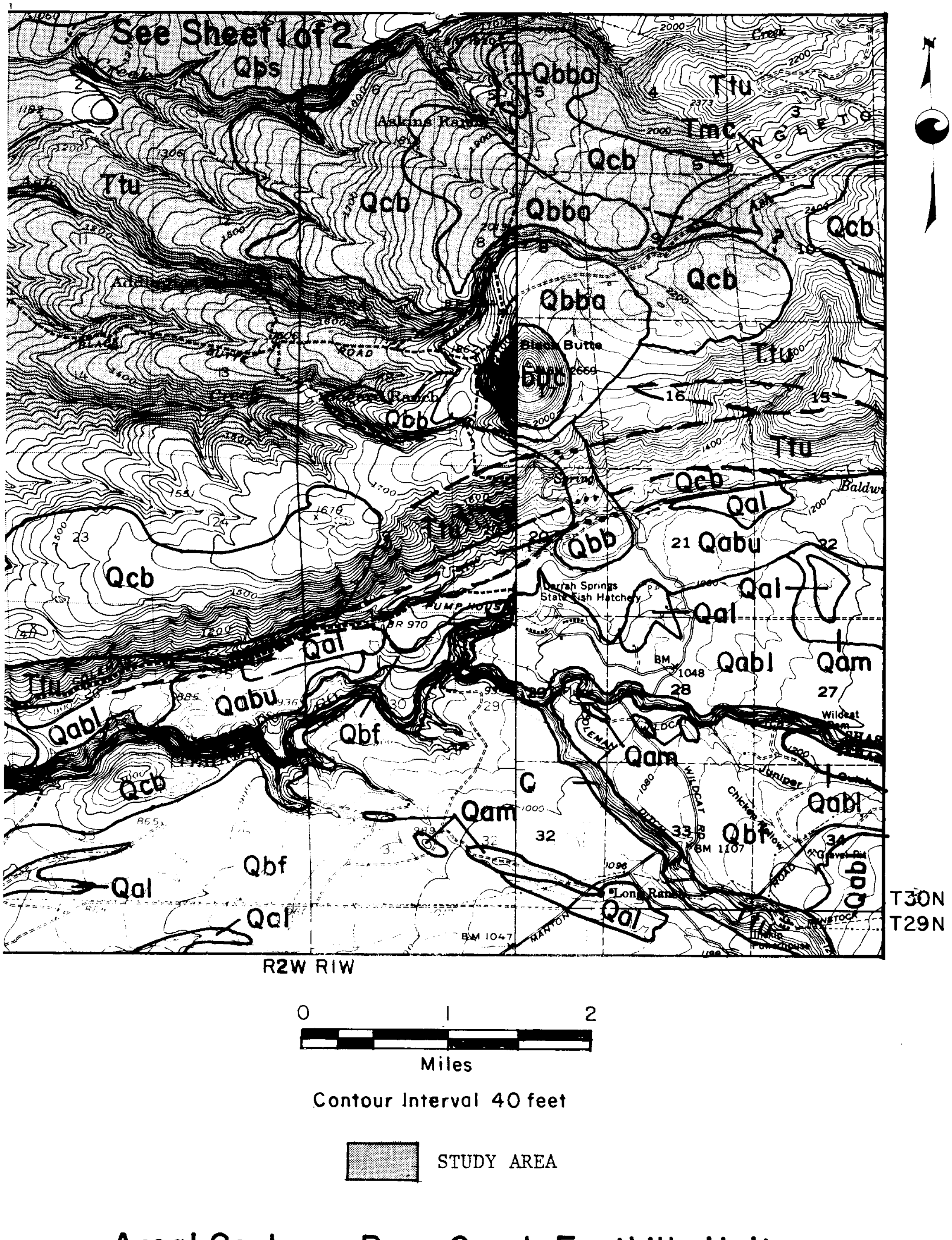
AXIS OF ANTICLINE



Areal Geology, Bear Creek Foothills Unit

Sheet 2 of 2 Sheets

Capping the Tuscan are Quaternary basalt flows. These underlie much of the unit and range in thickness from 10 to 40 feet in the west and up to about 250 feet in the east.

Quaternary alluvial fan depoaits of sand to cobble-size material in a sandy-silty matrix locally overlie older geologic units in the western half of the unit. They range in thickness from a foot or two to as much as 200 feet (USGS, 1980). These deposits were derived from erosion of the upland volcanic terrain to the east and are, depending on the investigator, usually classified as the Red Bluff Formation or an equivalent unit.

Recent alluvial deposits locally occupy stream channels and floodways. They consist of sand to boulder-size material and range from 1 to 20+ feet in thickness.

Occurrence of Ground Water

In evaluating the ground water resources in the Bear Creek Foothills unit, 113 well drillers' reports were reviewed. They were grouped in order of the wells' geographic location in the unit, east to west. Well depth, yield, and specfic capacity data are summarized in Table 3.

TABLE 3

SUMMARY OF BEAR CREEK FOOTHILLS UNIT WELL LOG DATA

Wells in Range (MDBM):	Yield (gpm) Average	Yield (gpm) Range	Well Depth (ft) Average	Well Depth (ft) Range	Specific Capacity (gpm/ft) Average	Specific Capacity (gpm/ft) Range
Range 1 west (42 wells)	19.7	0 to 160	260	87 to 582	0.4	0.01 to 2.5
Range 2 west (52 wells)	18.8	4 to 50	219	61 to 370	0.8	0.1 to 8.3
Range 3 west (19 wells)	31.1	7 to 100	167	68 to 284	4.1	1.1 to 5.0

The data in Table 3 show that well depths decrease, specific capacities increase, and well yields generally increase, in a westerly direction. Additionally, reported depths to water tended to follow this same trend--deepest in the east and shallowest in the west. These trends are the result of gentler sloping terrain in the western part of the unit and the changing character of the aquifer material, east to west.

The availability of ground water in the eastern part of the unit (Range 1W) near Black Butte is uncertain. Shallow perched ground water was encountered in a few wells and was later "lost" while drilling deeper. Wells drilled into the Chico Formation have reported yields ranging from zero to 160 gpm. In these wells that encountered water, it was usually confined ground water and rose to the surface in some instances. To the west, the availability of ground water is apparently more certain--there are no well drillers' reports on file for dry holes here, and even the lowest-yielding well (4 gpm) is adequate to supply normal domestic needs.

Recharge is mainly from rainfall. Streamflow does contribute to recharge, though generally below the 1,000-foot elevation; above this, the streams are gaining and represent reaches of ground water discharge. Based on evapotranspiration (ET), runoff, and deep percolation data for other nearby areas (Appendix B) recharge during a typical year may approach 5 inches in areas of trees and brush and up to 3 inches in the grasslands. During wet years, it may be two to three times these amounts. In dry years, no recharge from rainfall is likely to occur.

The direction of ground water flow in the unit is generally westward, though topographic relief influences it locally. In the eastern part of the unit, where vertical relief is 200 feet or more over short horizontal distances, ground water probably flows from the area of high relief to areas of low relief and discharges to the surface for the occurrence of perennial streams. Ground water flowing through the unit eventually finds its way to the Redding ground water basin as subsurface inflow.

Ground Water Development Potential

The ground water development potential in the Bear Creek Foothills unit is generally good. In the eastern third of the unit near Black Butte, ground water occurrence is unpredictable and "dry holes" are not uncommon. Elsewhere in the unit, ground water is usually found at reasonable depths and in sufficient quantities for domestic purposes. Here, as in other areas of volcanic terrain, ground water contamination from septic tank effluent is a real and present threat. Poor quality saline ground water may be found at depth in wells producing from the Chico Formation though its occurrence has not been documented.

Big Eddy Unit

The Big Eddy unit is in the southwest margin of Fall River Valley, 1 to 3-1/2 miles south of Fall River Mills (Figure 6). The unit consists of about 1,300 acres in Sections 6, 7, and 18, T36N/R5E/MDBM. Ranging in elevation from 3,275 to 3,600 feet, it is lightly vegetated with oak, pine, and brush.

Local Geology

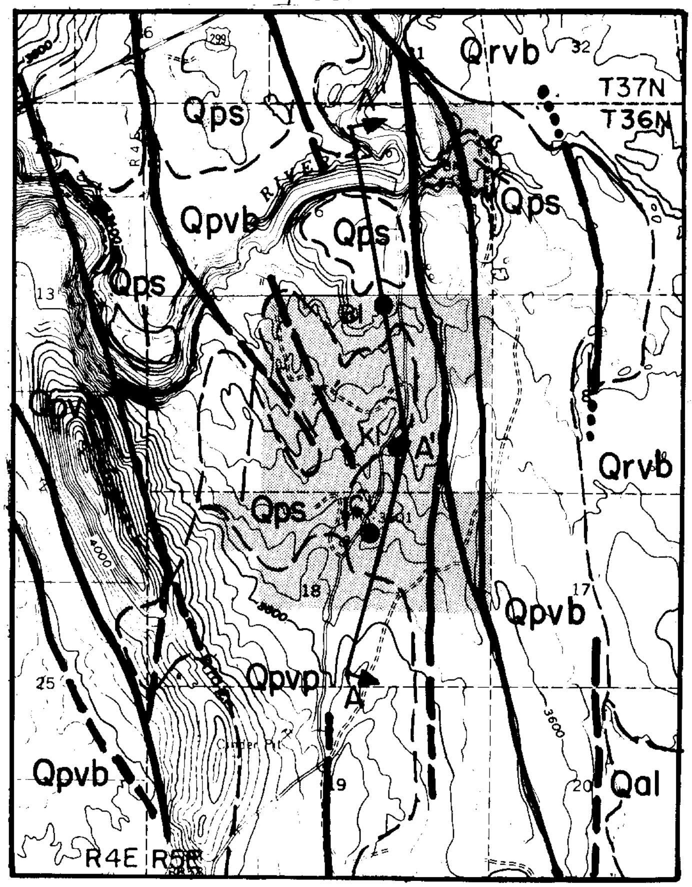
The Big Eddy unit, within the Modoc Plateau Geomorphic Province, is underlain by a succession of Quaternary volcanic rocks and continental deposits. Three nearly vertical normal faults, which are associated with the complexly faulted graben that forms Fall River Valley, dissect the unit (Figure 6). A previously unmapped fault is exposed in a road cut near the center of section 7, T36N/R5E. Its trace in the cut extends to within 6 inches of the ground surface and as such, it may be considered recently active.

The volcanic rocks are Pleistocene and Recent vesicular olivine basalt flows and Recent ash and Lapilli tuff. These rocks are moderately to highly permeable and form important aquifers when situated below the water table. The ash and Lapilli tuff deposit (Qpvp on Figure 6) ranges in thickness from less than a foot to 60 or 70 feet. These pyroclastic rocks overlie the continental deposits in the south part of the unit and are intermixed with them northward. Individual basalt flows range from 10 to 50 feet thick though the cumulative thickness of these flows is unknown. These generally underlie both the continental deposits and pyroclastic rocks though a few well logs show 20 to 50-foot sections of basalt overlying them.

The continental deposits are near-shore deposits and are evidence of an ancestral lake that covered Fall River Valley during Pleistocene time. Overflow of the lake and subsequent down-cutting of the Pit River Canyon southwest of Fall River Mills resulted in its drainage. Within the unit these deposits are encountered in some wells at depths ranging from the ground surface to 100 feet below ground surface and range from 50 to 140 feet in

SOURCE: Modified from DWR, 1961

Figure 6



0 1 2

Miles

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EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qrvb	Recent Basalt
Qpvp	Pleistocene Pyroclastic Rocks
Qpvb	Pleistocene Basalt
Qps	Near-Shore Deposits

CONTACT
Dashed where approximately located.

● CI WATER LEVEL MEASUREMENT WELL

FAULT
Dashed where approximately located, dotted where concealed

A A"

LOCATION OF GEOHYDROLOGIC SECTION

STUDY AREA

Areal Geology, Big Eddy Unit

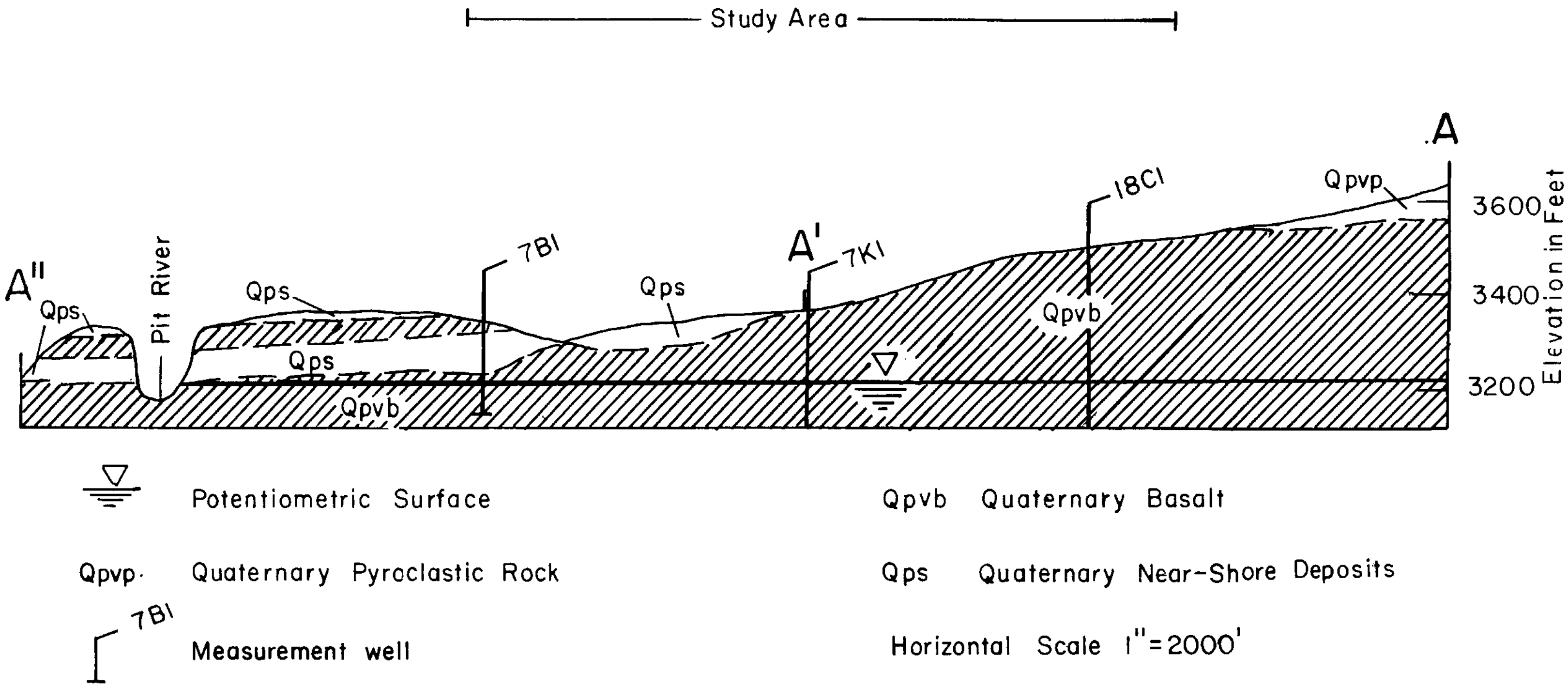
thickness. They range from gravel conglomerate to tuffaceous sand and clay, and are highly to moderately permeable.

Occurrence of Ground Water

The fractured basalt flows underlying the area are the main water bearing rocks in the Big Eddy unit. The near-shore deposits and pyroclastic rocks may yield some ground water but because they are generally above the water table or potentiometric surface, they are not important aquifers.

Water levels in three wells were measured during this study and well drillers' reports for thirteen wells were evaluated. The water level measurements show that the ground water is confined and that the potentiometric surface remains almost constant at an elevation of about 3,220 feet throughout the unit (Figure 7), varying by less than a foot or two between spring and fall. This suggests that there is hydraulic continuity between the fractured basalt aquifer, which underlies the Big Eddy unit, and the Pit River, located just to the north and northwest at an elevation of 3,200± feet. This continuity can be either a direct connection between the river and the aquifer or an indirect one involving flow downward and laterally along faults where they intersect the river, and then horizontally into the aquifer. This latter hypothesis is preferred for the following reasons:

1. The potentiometric surface in the Big Eddy Unit is 20 or more feet higher than the river's surface; this would tend to preclude ground water flow from the river towards the area of concern.
2. The two prominent faults in the eastern part of the unit intersect the river at elevations ranging from 3,200 to 3,240 feet. Further, according to DWR (1961), faults in the Fall River Valley area ".....create shattered zones (within the volcanic rocks) which serve as vertical and horizontal paths of high permeability."
3. Data in well drillers' reports suggest that the ground water here is confined, leading to static water levels as much as 150 feet above the producing zone. A highly permeable fault zone nearby that interesects the aquifer at depth could account for the reported rises in water levels.
4. The near static water levels in the measurement wells suggest that an equilibrium exists between the aquifer and the aquifer's forebay.



Geohydrologic Cross-Section, Big Eddy Unit

Figure 7

The confining zone above the aquifer would probably be a thick, unfractured basalt flow or a flow in which the fractures have "healed".
Regardless of the route taken by ground water, the elevation of the top of the producing zone is about 3,150 feet. Hence, the cost of developing the resource is a function of the ground surface elevation of the well site. Table 4 is a summary of the data contained in the well drillers' reports of wells producing water from the fractured basalt aquifer.

TABLE 4

SUMMARY OF BIG EDDY UNIT WELL LOG DATA

Yield (gpm)		Well Depth (ft)		Reported Rise (ft)1/	
Average	Range	Average	Range	Average	Range
13-1/2	8 to 20	275	165 to 455	66	0 to 150

Ground Water Development Potential

The availability of ground water in the Big Eddy unit is adequate for the existing development, is of good quality, and appears capable of sustaining moderate growth. The depth to ground water and its apparent confinement will tend to keep the resource safe from contamination. However, faults through the area are potential avenues for contaminants and should be considered when siting waste water disposal systems, or solid waste disposal areas.

Cassel Unit

The Cassel unit consists of eight separate parcels, totaling almost 2400 acres, located generally east of State Highway 89, between Cassel and the Pit River (Figure 8). The parcels lie at about 3200 feet elevation and are vegetated primarily with brush and locally dense stands of fir and cedar. The area is relatively densely developed with the highest concentration around the village of Cassel.

1/The difference between the standing water level after well completion and the depth of first water.

Local Geology

The Cassel Unit lies within the Modoc Plateau/Cascade Geomorphic Province boundary. Prominent northwest- and north-trending normal faults dissect the area and create most of the area's topographic relief. Geologic units in the area range from Quaternary alluvium and basalt flows to Pliocene volcanic rocks and continental deposits (Figure 8).

In the Hat Creek-Rising River area and along the Pit River, the Quaternary alluvium is clay to boulder-sized material. Well drillers' reports show the alluvium to range from 1 to 38 feet in thickness. Alluvial deposits in the Crystal Lake area are likely to be predominantly clay to sand-sized material due to the basin-like character of the area and the absence of any well-defined drainages. The Recent and Pleistocene basalts are highly fractured and pervious.

Brush Mountain, a mile west of Cassel, is composed of Pliocene basalt and cinders and is complexly faulted; younger geologic units lap onto or are faulted against its flanks. Because of the faulting and resultant secondary permeability in the basalt and the presence of interstratified cinder beds, the mountain is extremely permeable and porous.

The Pliocene continental deposits are evidence of an ancient lake that once existed in this area. The lake subsequently drained and its deposits were buried beneath Pleistocene basalt flows. These deposits crop out where the Pit River and Hat Creek have eroded through the younger, overlying rocks or where faulting has lifted them above the surrounding younger volcanic rocks. These deposits range from diatomite and diatomaceous earth to cobble and boulder conglomerate; permeability ranges from very low to high. Near Cassel, these deposits are usually found at depths of 60 to 90 feet. North of Highway 299 they are reported at 80 to 100 feet.

Occurrence of Ground Water

Depth to ground water in the Cassel unit varies as does, well yields and aquifer characteristics. Complex of faulting and a variety of geologic units combine to produce this variability.

Faults, particularly those associated with Brush Mountain, appear to act as conduits for ground water, draining aquifers of their water. One well in the northwest quarter of Section 36, T36N/R3E was drilled more than 400 feet

EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qrvb	Recent Basalt
Qpvb	Pleistocene Basalt

TERTIARY

Tpl	Pliocene Lake Deposits
Tpvb	Pliocene Basalt

● R1 WATER LEVEL MEASUREMENT WELL

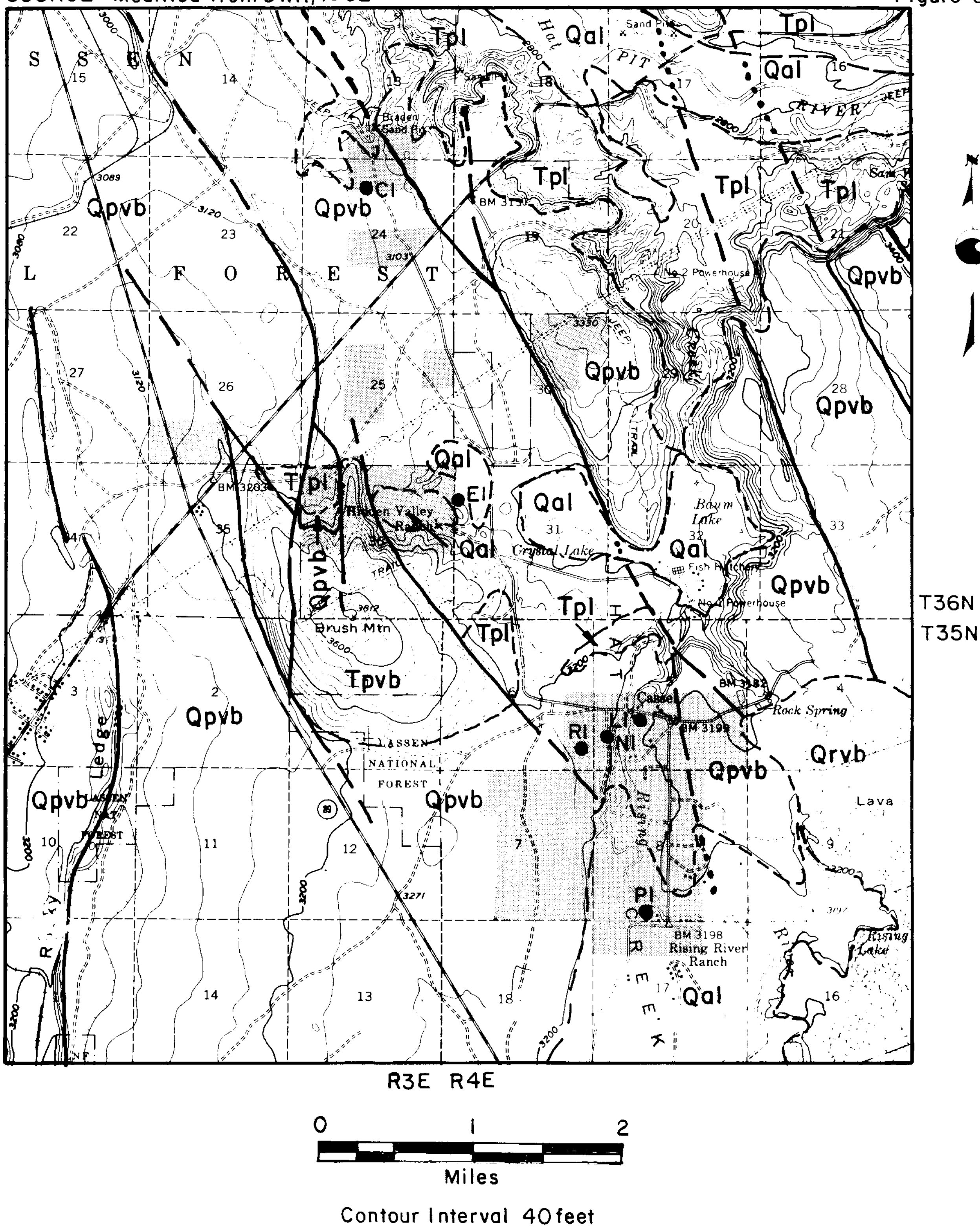
CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located,
dotted where concealed.

STUDY AREA

SOURCE: Modified from DWR, 1962

Figure 8



Areal Geology, Cassel Unit

feet without finding water. Other wells in the area show an increasing depth to water with nearness to faults.

Relatively shallow ground water (30 to 40 feet below ground surface) is found in the Cassel area next to Hat Creek and Rising River. Water level measurements in four wells here indicate that these streams are losing water to the subsurface and are thus major sources of ground water recharge. A few wells here have been drilled through the alluvium and Pleistocene basalt into the Pliocene continental deposits. Based on these meager data in the well drillers' reports, the Pliocene deposits contain unconfined ground water. Hence the ground water in the upper alluvium and fractured basalt would appear to be perched ground water. North of Highway 299 the fractured basalt is barren of ground water. Here the underlying Pliocene continental deposits form the aquifer and contain unconfined ground water.

Reported well yields in the Cassel unit range from 10 to 320 gpm. Wells producing from the Quaternary basalts have reported yields of 15 to 320 gpm; most wells yield 15 to 40 gpm. Wells producing from the Pliocene continental deposits yield 10 to 40 gpm with an average yield of 24 gpm. One well drilled into the Pliocene volcanic rocks of Brush Mountain, as mentioned above, produced no water.

Ground water flow in the Cassel Unit is generally northward, with flow direction suspected to be influenced by faults. The volume of flow cannot be estimated, but is probably great owing to the highly fractured character of the Quaternary and Pliocene volcanic rocks and permeable nature of the sand-to-boulder-size fraction of the Pliocene continental deposits.

Recharge of the volcanic aquifer is mainly from deep percolation of streamflow. The Pliocene continental deposits probably are recharged from vertical leakage from the overlying volcanic rocks and possibly from ground water draining downward along faults.

TABLE 5

GROUND WATER DEVELOPMENT POTENTIAL IN THE CASSEL UNIT

Township & Range	Parcels in Section(s)	Ground Water Development Potential	Comment
T36N/R3E	36	Poor	Absence of ground water noted in NW1/4 of section. Possible limited supply of shallow ground water in NE1/4.
T36N/R3E	26	Questionable	No data. Proximity to fault suggests deep ground water (<200 ft).
T36N/R3E	25	Fair	Fractured basalt aquifer. Depth of ground water increases to the west.
T36N/R3E	13 & 24	Good	Aquifer consists of Pliocene continental deposits.
T36N/R4E	30	Questionable	No data. Topography and proximity to fault suggest deep ground water (<200 ft).
T35N/R4E	5,6,7,8, & 17	Good	Probable shallow perched aquifer and deep aquifer. Depth to ground water generally increases with distance from Hat Creek and Rising River.

Ground Water Development Potential

Based on data for 42 wells and water level measurement in 6 wells in the Cassel unit area, the development potential for most of the areas of concern is fair to good. Reported well yields are adequate for domestic needs and only minor fluctuations in the elevation of the water table suggest minimal seasonal change in aquifer storage. Table 5 summarizes the ground water development potential of each parcel considered. As in other areas of volcanic rock and shallow ground water, water quality degradation from septic tank effluent is possible. Some wells near Cassel are reported to have experienced this, and the local water district has abandoned its shallow wells for deep wells for this reason.

Eastern Klamath Mountains Unit

The Eastern Klamath Mountains unit consists of about 42 square miles (26,900 acres) that extend from near the town of Montgomery Creek, 22 miles to the southwest, to the east end of Bear Valley, 5 miles north of Bella Vista. Highway 299E passes through or skirts most of the unit in a general northeast-southwest direction. The topography ranges from uplands of gentle relief to steep-sided canyons cut into the uplands by Little Cow Creek and its tributaries. Vegetative cover is predominantly brush, though stands of Digger pine, Ponderosa pine, or oak are locally present.

Local Geology

Permian to Triassic rocks of the Eastern Klamath Belt (Irwin, 1966) of the Klamath Mountains Provice dominate the area's geology, though, locally, younger sedimentary and volcanic rocks of the Great Valley and Cascade Range Provinces unconformably overlie them. Figures 9 and 9a show the areal geology of the unit and adjacent area.

The Eastern Klamath Belt consists of metamorphosed shale, sandstone, conglomerate, lava flows, pyroclastic rocks, and limestone. In the area studied for this report, various investigators have divided it into as many as six separate formations based on lithologic characteristics and stratigraphic relationships. These formations, in decreasing geologic age are (1) Dekkas andesite (Permain), (2) Bully Hill rhyolite (lower to middle Triassic), (3) Pit Formation (middle to upper Triassic), (4) Hosselkus limestone (upper Triassic), (5) Brock shale (upper Triassic), and (6) Modin Formation (upper Triassic).

The Dekkas andesite is chiefly fragmental lava flows and pyroclastic rocks but includes beds of mudstone and tuffaceous sandstone (USGS, 1961). It is conformably overlain by the Bully Hill rhyolite, and lithologically similar rocks are found in each. The Dekkas andesite is exposed in the unit as the crest of a northwest-trending anticline that intersects Highway 299E southwest of Ingot.

The Bully Hill rhyolite consists of silicic lava flows and pyroclastic rocks conformable between the underlying Dekkas andesite and the overlying Pit Formation. It is exposed as four northwest-trending bands that intersect Highway 299E about two miles northeast of Ingot, just east of Ingot, in the area of Diddy Wells, and at Woodman Hill, six miles east of Bella Vista.

The Pit Formation consists of metamorphosed shale, mudstone, pyroclastic rocks, and minor beds of siltstone, limestone, and lava. It underlies most of the unit from near Round Mountain westward.

Lying conformably over the Pit Formation is the Hosselkus limestone. It is a minor constituent of the area's geology, being not more than 200 feet thick (Hilton 1975). However, it contrasts markedly with the other formations in the area; it forms pronounced cliffs and weathers to a light grey color.

The Brock shale is predominantly a dark grey metashale with interbedded tuffs and tuffaceous sandstones. It is conformable with the underlying Hosselkus limestone and the overlying Modin Formation. Hilton (1975) suggests that the Brock shale be considered the basal member of the Modin Formation, and, as such, he mapped the two as one unit. The Modin Formation consists of beds of tuffaceous sandstone, metashale, and conglomerate. It and the Brock shale are exposed in the unit in the Cedar Creek drainage and extend northward to the Pit River and beyond. To the east, they are unconformably overlain by the younger rocks of the area.

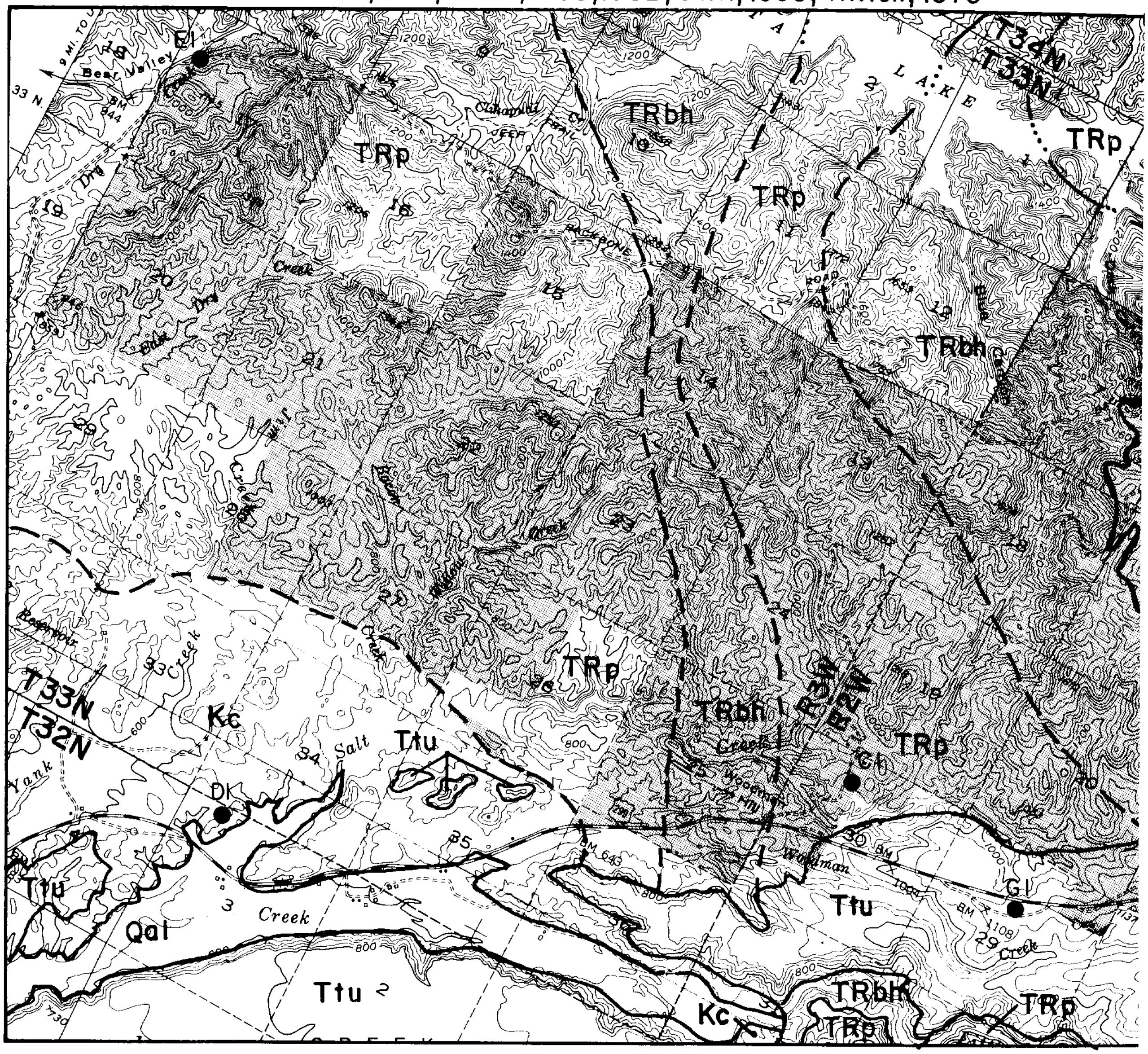
Overlying the Permian and Triassic rocks in the Eastern Klamath Mountains unit are sedimentary and volcanic rocks which range in age from Cretaceous to Recent. Erosional unconformities separate these from older formations and they may overlie all or any of the older formations. These relatively younger formations are (1) the Chico Formation (Cretaceous), (2) the Montgomery Creek Formation (Eocene), (3) the Tuscan Fromation (Pliocene), and (4) alluvium (Recent).

Remenants of the Chico Formation, which is widespread southwest of the unit, are exposed in the Little Cow Creek and Cedar Creek drainages. These represent the basal portion of the Chico Formation and consist of conglomerate and course sandstone with interbedded sandy shale and shale.
They rest unconformably on the Triassic rocks of the area and attain a maximum thickness of 320 feet in Section 33, T34N/R1W (Hilton, 1975).

The Montgomery Creek Formation consists of conglomerate, sandstone and minor beds of sandy shale, claystone, and coal seams. In the Cedar Creek drainage and to the east, in the Montgomery Creek drainage, it is markedly more coarse than in other areas of Shasta County, suggesting a close proximity to its source here. It unconformably overlies Cretaceous and Triassic rocks in the area and is unconformably overlain by the Tuscan Formation.

The Tuscan Formation locally lies unconformably over all of the older formations mentioned. In the eastern Klamath Mountains unit it consists

SOURCE: Modified from USGS, 1961; CDMG, 1960, 1962; DWR, 1958; Hilton, 1975



EXPLANATION

QUATERNARY
- Qal   Alluvial Deposits

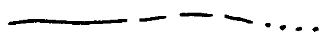
TERTIARY
- Ttu   Tuscan Formation
- Tmc   Montgomery Creek Formation

PRE-TERTIARY
- Kc   Cretaceous Chico Formation
- TRbm   Brock Shale and Modin Formation
- TRp   Triassic Pit Formation
- TRbh   Triassic Bully Hill Rhyolite
- Pd   Permian Dekkas Andesite

AXIS OF ANTICLINE, Showing plunge

AXIS OF SYNCLINE

● Cl   WATER LEVEL MEASUREMENT WELL



CONTACT
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FAULT
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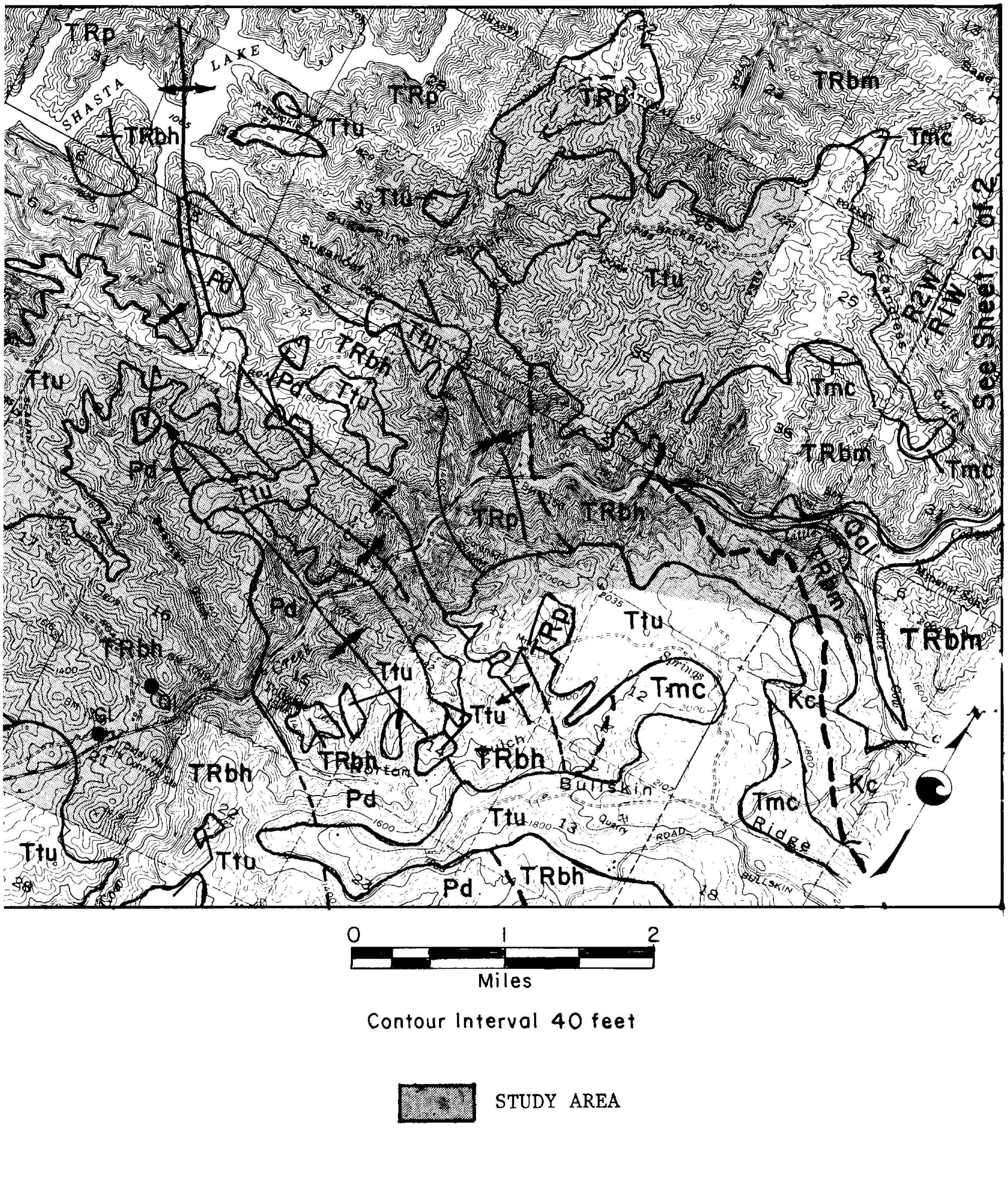
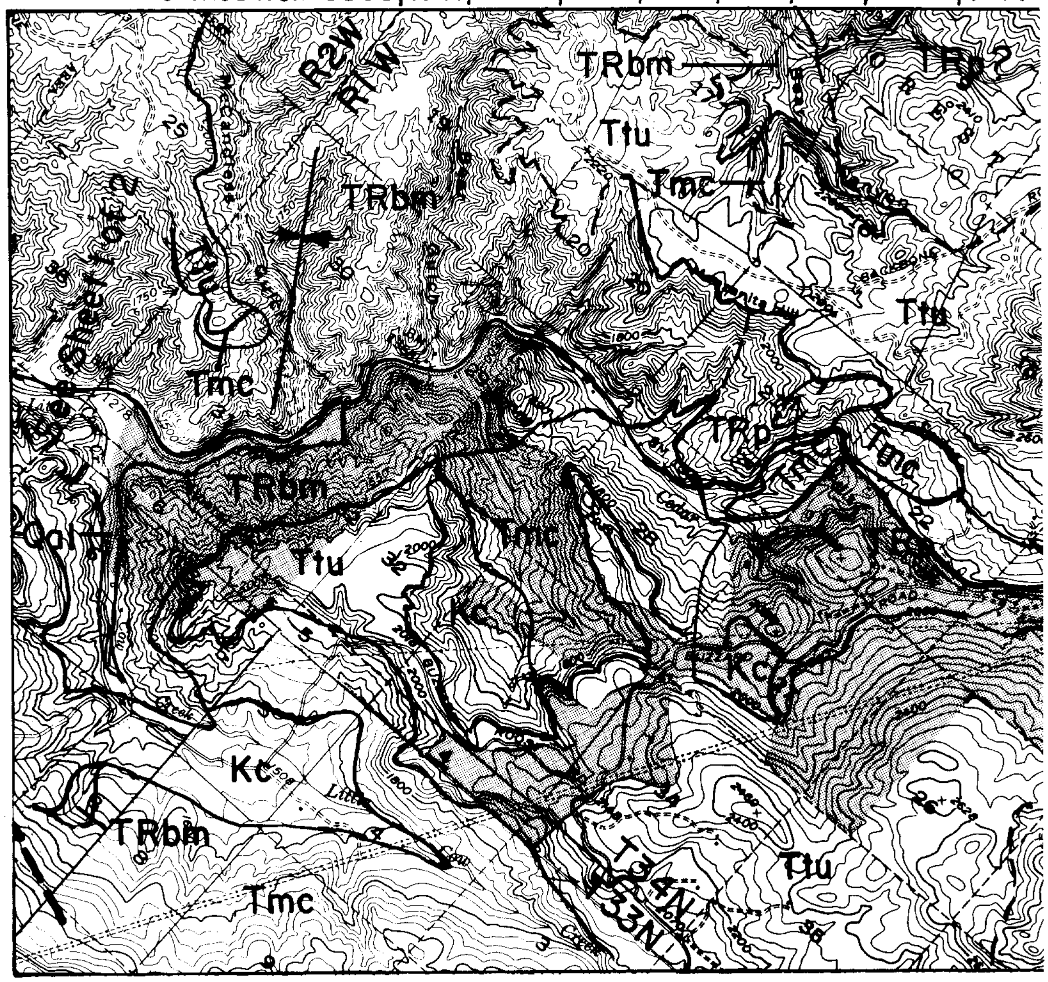


Areal Geology, East Klamath Mountains
Sheet 1 of 2 Sheets

SOURCE: Modified from USGS, 1961; CDMG, 1960, 1962; DWR, 1958; Hilton, 1975

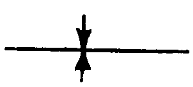


EXPLANATION

QUATERNARY
- Qal Alluvial Deposits

TERTIARY
- Ttu Tuscan Formation
- Tmc Montgomery Creek Formation

PRE-TERTIARY
- Kc Cretaceous Chico Formation
- TRbm Brock Shale and Modin Formation
- TRp Triassic Pit Formation

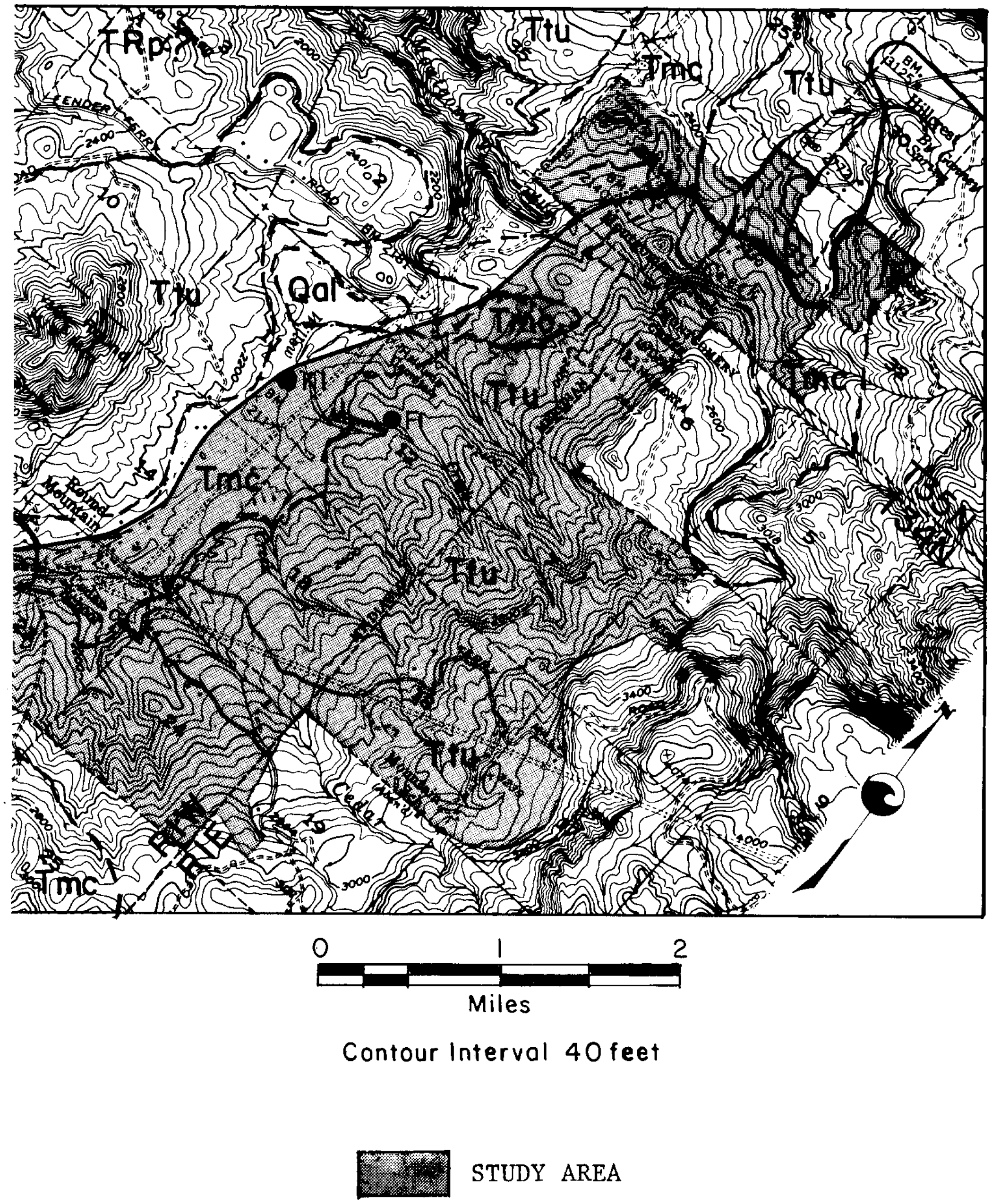


AXIS OF SYNCLINE

● F1 WATER LEVEL MEASUREMENT WELL

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located.



Areal Geology, East Klamath Mountains
Sheet 2 of 2 Sheets

primarily of mudflow tuff breccia with minor interbeds of welded tuff and conglomerate and is locally capped by basaltic lava.

A moderate amount of alluvium occupies the relatively broad valley of Little Cow Creek upstream from the confluence of Cedar Creek. Based on data from one well drilled here, it consists primarily of cobble and boulder-sized material in a sand matrix with a maximum thickness in excess of 50 to 60 feet. A thin veneer of alluvium, probably less then 20 feet thick, covers the Montgomery Creek Formation in the broad valley that trends northward from the town of Round Mountain. Here it is mainly gravel and sand with minor beds and lenses of silt and clay.

Occurrence of Ground Water

In evaluating the occurrence of ground water in the eastern Klamath Mountians unit, well drillers' reports for 99 wells were evaluated and water levels in 5 wells were measured monthly. Because very few wells were field located in the unit, the geologic formations encountered by each well were categorized in three groups according to the well drillers' descriptions. These three categories are (1) Permian and Triassic rocks, (2) rocks of the Chico and Montgomery Creek Formations, and (3) volcanic rocks of the Tuscan Formation. In some instances, a well would penetrate two or more of these geologic categories. In such cases, the well was placed in the category determined to be the main source of ground water in the well. Well depth, yield, and specific capacity data for each is summarized in Table 6.

TABLE 6

SUMMARY OF EASTERN KLAMATH MOUNTAINS
WELL LOG DATA

	Yield (gpm)		Well Depth (ft)		Mean Specific Capacity (gpm/ft)
	Avg.	Range	Avg.	Range	
Permian and Jurassic Rocks	12.9	0 to 80	163	60 to 264	0.3
Chico and Montgomery Creek Formations	12.6	0 to 50	203	93 to 405	0.2
Tuscan Formation	30.3	0 to 100	129	36 to 250	0.5

Permian and Triassic Rocks. Fifty-eight of the 99 well reports evaluated were determined to represent wells producing ground water from the Permian and Triassic rocks of the unit. Table 6 shows that well depth and yield cover a relatively wide range of values.

Based on data from the monthly well measurements, two factors combine to determinie both depth to water and well yield. These are topography and depth of weathering (secondary porosity). Relatively high-yielding, shallow wells are common in draws and valley bottoms where weathering of the bedrock is deepest. Deeper, low-yielding wells are common in upland areas where weathering is least. Annual fluctuations of the water table are also affected by typography, with the greatest change occurring in upland areas.

Recharge is from rainfall and is greatest where soils are thickest. In the upland areas of the unit, vegetation type is a good index of soil character. Digger pine and Manzanita are generally found where soils are thin and ground water is sparse. Stands of pine, cedar, and deciduous trees indicate generally deeper soils and potentially available ground water.

Ground water, like surface water, tends to drain away from the hills to the valleys. Thus discharge from the uplands recharges the lowlands and accounts for the modest fluctuations of the water table in these areas.

Chico and Montgomery Creek Formations. Twenty-seven of the well drillers' reports evaluated were determined to represent wells producing ground water from the Chico and Montgomery Creek Formations. These tended to be deeper, generally yielded less water, and have specific yields slightly less than the Permian and Triassic rocks. This is attributable to their apparent lack of well developed secondary permeability and porosity and diminished primary permeability and porosity.

The sandstone and conglomerate beds of both formations are the chief water-yielding strata. The interbedded shale and siltstone confine water below them, and some wells in the Round Mountain area are reported to be flowing artesian wells upon completion.

Recharge of the sandstone and conglomerate beds is probably from streamflow, rainfall, and from lateral movement of ground water from the older formations across the contact. This contact generally takes the form of relatively fresh fractured rock overlain by a coarse basal conglomerate.

Tuscan Formation. Fifteen of the well drillers' reports were for wells completed in the Tuscan Formation. Most were reported to yield 10 to 30 gpm, though two had reported yields of 100 gpm. These relatively high well yields are the result of moderate to high permeability and porosity of the Tuscan rocks in this part of Shasta County.

Recharge is from precipitation only and totals an estimated 10 to 15 inches during a normal year. Rainfall percolating into the subsurface moves downward to the base of the Tuscan Formation and then laterally to discharge as springs and seeps along the contact where it intersects the land surface.

Ground Water Development Potential

The ground water development potential in the eastern Klamath Mountains unit ranges from moderate to good. All geologic formations in the unit are capable of yielding sufficient quantities of good quality ground water to wells for domestic and stock needs. In the portion of the unit underlain by the Permian and Jurassic rocks, topography seems to control the depth to water and well yields. In the other areas of the unit, primary permeability and porosity, which can vary significantly within a formation, influence the well yields.

Wells drilled into one formation, just upslope from its contact with an older formation, are likely to have yields and specific capacities characteristic of the older formation.

Hat Creek Unit

The Hat Creek unit consists of three parcels totaling about 2,800 acres in Hat Creek Valley, between Cassel and Old Station (Figure 10). The unit lies between 3,250 and 3,600 foot elevation and is vegetated with meadows, brush, and stands of fir and cedar.

Local Geology

The Hat Creek Unit is within the Modoc Plateau Geomorphic Province. Its geology is dominated by recent volcanism and many northwest-trending normal faults. The valley here is 1 to 4 miles wide and is almost entirely underlain by the Recent Hat Creek lava flow. On the west is the upthrown end of an easterly dipping fault block composed of Pliocene basalt. To the east are similar fault blocks which form Hat Creek Rim.

The Hat Creek lava flow is a pahoehoe basalt flow that was discharged from fissures south of Old Station, possibly within the past 2,000 years (Anderson, 1940). Lava tubes are rather common throughout the flow and range from about 1 foot to 15 feet in height. The thickness of the flow is not known, but Anderson (1940) suggests it is thickest along the eastern margin of the valley, owing to the easterly tilt of the basement fault block.

A veneer of alluvial material overlies the Hat Creek lava flow in places along the western margin of the valley. Water well drillers' reports show this to consist of clay-to-gravel-sized material that range in thickness from 1 to 18 feet.

In the subsurface, the dominant rocks are fractured lava flows. Layers of cinders are encountered in some wells drilled near the western margin of the valley and are probably part of the Pliocene fault block.

Occurrence of Ground Water

Water levels in five wells were measured during the study. From these data and information contained in the drillers' reports for 23 wells in the area, the depth of the water table, well yields, and ground water flow direction are made relatively predictable.

The elevation of the water table is fairly constant throughout the unit, varying some 30 to 40 feet from just north of Lincoln School to just south of Wilcox School, about 8 miles (Figure 11). The depth to ground water and hence the cost of developing the resource is a function of the ground surface elevation, which varies by 400 feet over the same 8 miles. The depth of the water table in the northern end of the unit is 50 to 70 feet, while at the southern end it is more than 300 feet.

Well yields, except for one well that is reported to produce about 400 gpm, average about 18 gpm, ranging from a low of 8 gpm to a high of 35 gpm. Most wells fall in the 12-to-20 gpm range. Data on drawdown during pumping are lacking in every report, so specific capacity estimates are impossible.

The direction of ground water flow is generally northerly, with a gradient of about 3 to 5 feet per mile. At the distal end of the Hat Creek flow, the water table elevation and ground surface elevation gradually merge to form Rising River.

Recharge in the unit is from percolation of precipitation, streamflow, and subsurface inflow. Recharge is very rapid due to highly jointed character

EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qrvb	Recent Basalt
Qrvp	Recent Pyroclastic
Qpvb	Pleistocene Basalt
Qpvp	Pleistocene Pyroclastic

TERTIARY

Tvb	Tertiary Basalt

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located, dotted where concealed.

● F1 WATER LEVEL MEASUREMENT WELL

A A'

LINE OF GEOLOGIC CROSS-SECTION

STUDY AREA

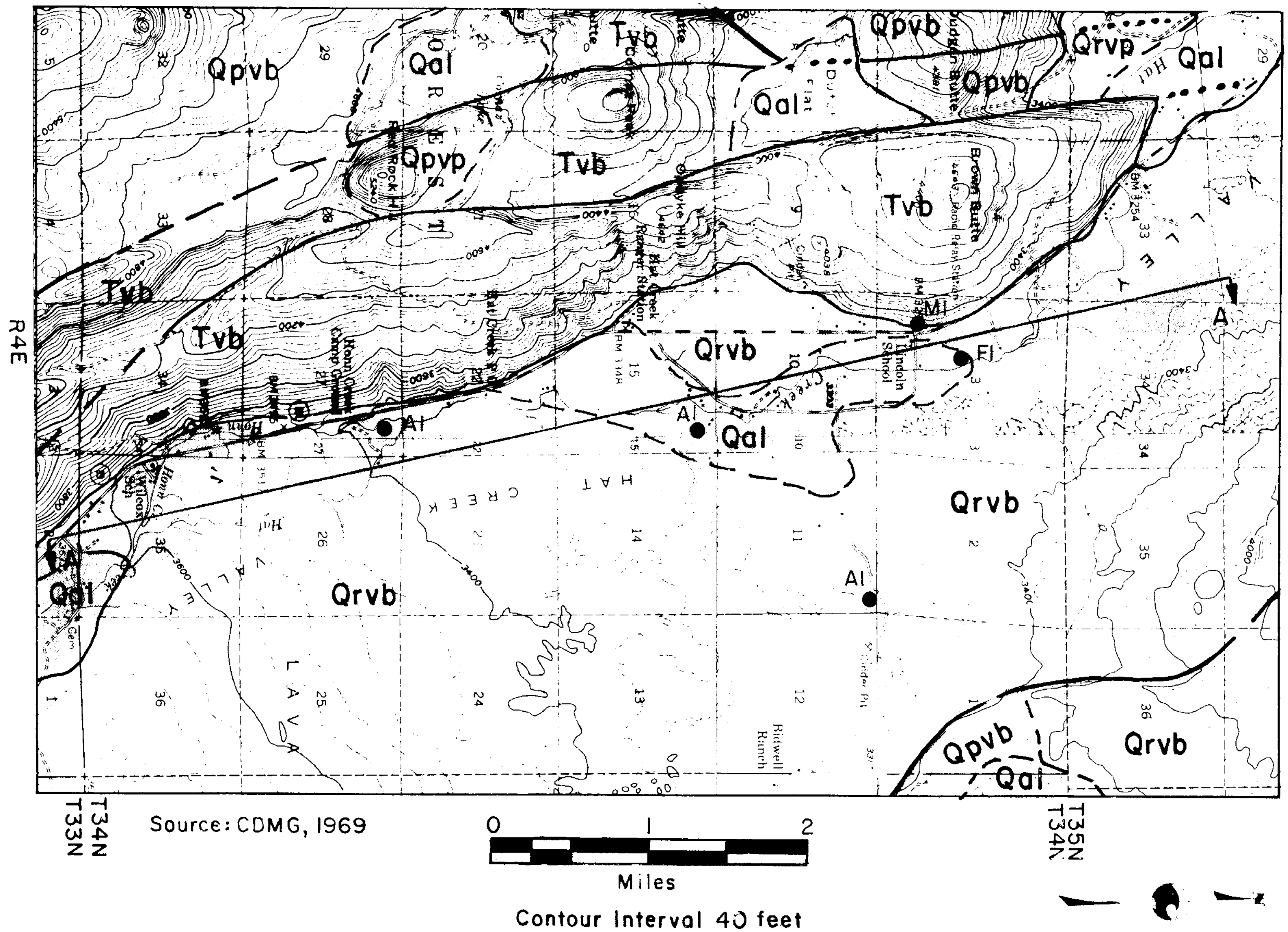
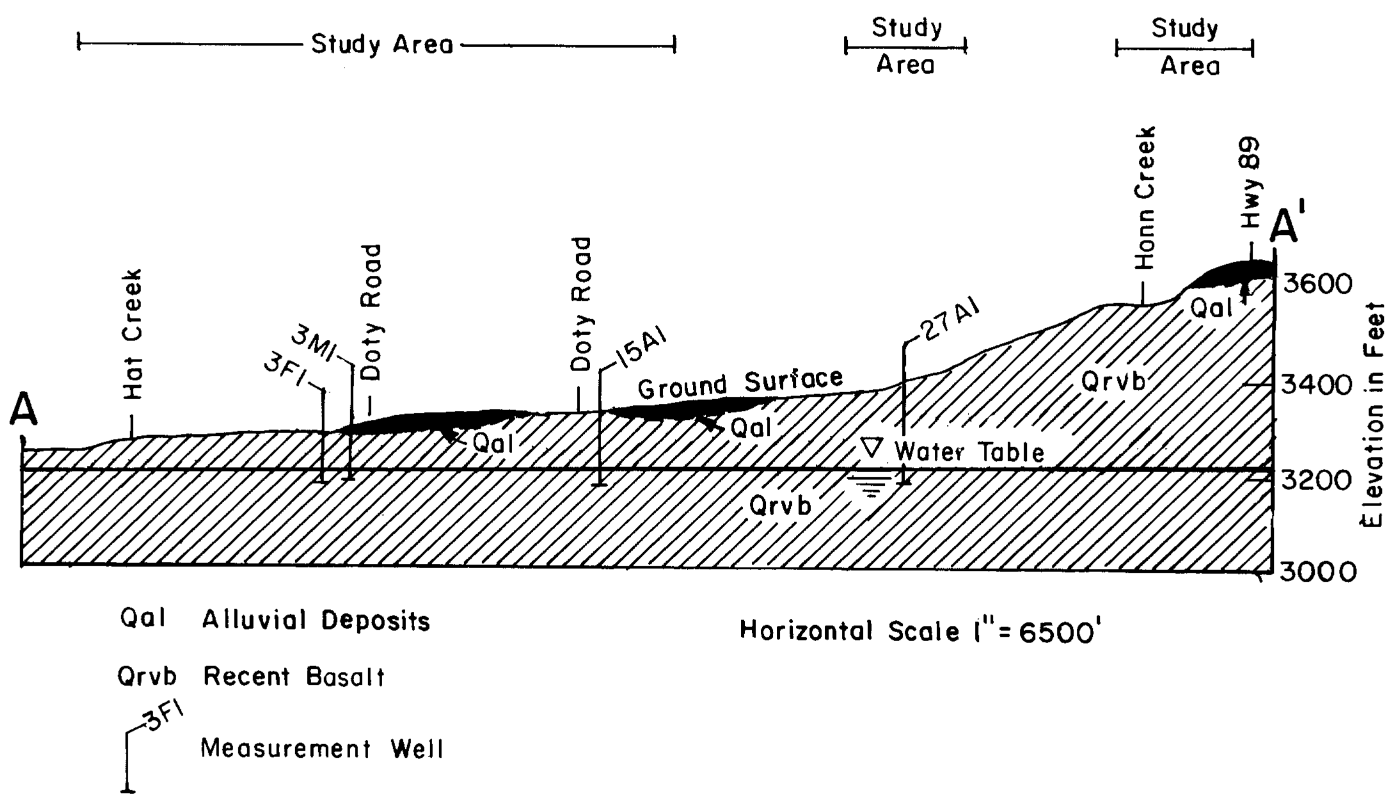


Figure 10

Areal Geology, Hat Creek Unit



Geohydrologic Cross-Section, Hat Creek Unit of the lava and presence of numerous lava tubes. The rate of recharge and transmissivity of the fractured rock aquifer can be estimated by using the observed flow from Rising River and its associated springs and the assumption that the entire flow is derived from ground water flow from Hat Creek Valley. Thus, a discharge at Rising River of about 690 acre-feet per day (DWR, 1964) or 350 cfs is a reasonable estimate of the volume of ground water flow, and hence recharge, in the Hat Creek Valley south of Rising River. Transmissivity of the aquifer can now be calculated using the formula:

$T = \frac{Q}{IL}$ where T = transmissivity in gpd/ft; Q = the volume of water, in gpd, moving through a cross section of the aquifer; I = the gradient of the water table; and L = the width in feet of the section considered. With Q equal to 2.26×10^8 gpd (350 cfs), I equal to 0.00057 (3 ft/mi) and L equal to 21,120 ft (4 mi, the distance between the valley-bounding faults), a transmissivity value of 1.88×10^7 gpd/ft (29 cfs/ft width of aquifer) is obtained. This is a very high value, but in light of the character of the volcanic aquifer, it is not beyond reason.

Ground Water Development Potential

Based on the estimated recharge rate, aquifer transmissivity, and average well yields, the ground water resource does not appear to be a constraint on the development of this unit. It must be noted that ground water development costs increase from north to south within the unit, and that the pervious nature of the rocks leads to the possibility of ground water contamination from septic systems.

Inwood Unit

The Inwood unit consists of about 7,200 acres between the 1,400 foot and 3,200-foot elevations on the western flank of the Cascade Range (Figure 12). Oak and Digger pine forest cover the lower elevations and give way to fir, cedar, and meadows at higher elevations to the east. The area is moderately populated; residential development is concentrated along State Route 44, the main transportation corridor to the Anderson-Redding area.

Local Geology

The geology in the Inwood unit is complex and reveals a long history of erosion, sedimentation, and regional volcanic activity.

The oldest rocks are bedded marine shale and sandstone of the Cretaceous Chico Formation. These crop out at various locations in and near the unit and are encountered at depth in some wells (Figure 12).

Locally overlying the Chico Formation is the Eocene Montgomery Creek, Formation. It consists of interbedded shale and sandstone and crops out generally north of the unit, in the Bear Creek canyon.

The Tuscan Formation, a succession of volcanic and associated sedimentary rocks, overlies both the Chico and Montgomery Creek Formation. The Tuscan rocks are predominantly tuff-breccia, with interbedded lava flows, tuff, and volcanic conglomerate, sandstone, and siltstone. The contact between the Tuscan and the underlying, older formations, is an erosional unconformity with moderate to high relief. This suggests that the Tuscan volcanic rocks flowed down and filled ancient deep stream valleys.

Capping the Tuscan Formation are Late Pliocene and Pleistocene lava flows. The Late Pliocene flow is a series of andesite lavas with minor amounts of interbedded tuff and tuff breccia (MacDonald, 1972). The Pleistocene lava consists predominantly of olivine basalt and is part of an large flow that extends west from the vicinity of Red Lake Mountain (about 6 miles northeast of Viola) nearly to Millville.

Occurrence of Ground Water

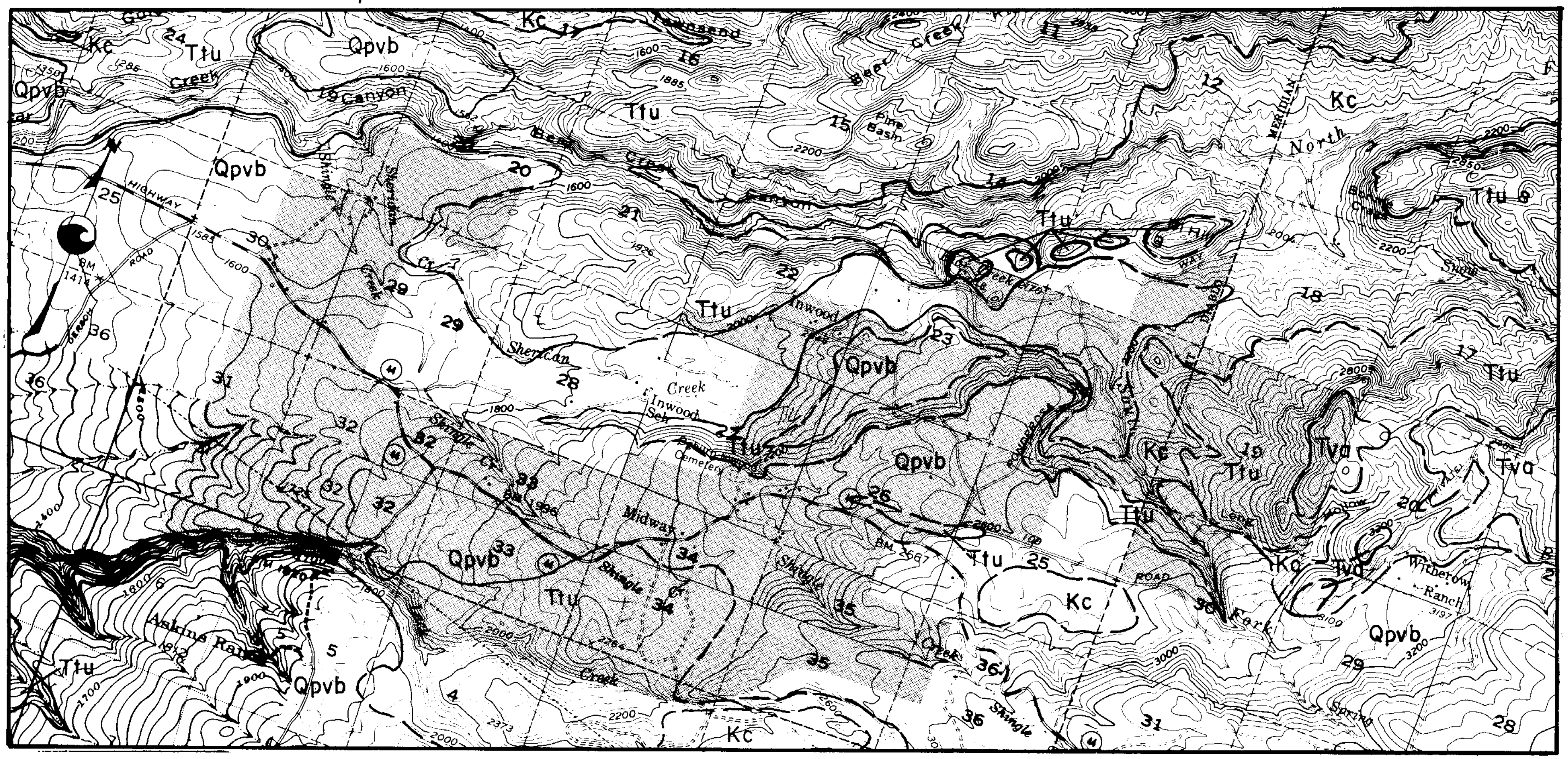
In evaluating the ground water resources of the Inwood unit, data contained in 73 well drillers' reports and water level measurements in 29 wells were analyzed. Depth and yield data from well drillers' reports are summarized in Table 7.

TABLE 7

SUMMARY OF INWOOD UNIT WELL LOG DATA

Depth (ft)		Yield (gpm)		Specific Capacity (gpm/ft)	
Average	Range	Average	Range	Average	Range
197	70 to 400	21	6 to 100	4.3	0.1 to 50

SOURCE: Modified from USGS, 1972



0 1 2
Miles

Contour Interval 40 feet

EXPLANATION

QUATERNARY

Qpvb Pleistocene Basalt

TERTIARY

Tva Pliocene Andesite
Ttu Tuscan Formation
Tmc Montgomery Creek Formation
Kc Cretaceous Chico Formation

CONTACT
Dashed where approximately located.

STUDY AREA

Areal Geology, Inwood Unit

Figure 12

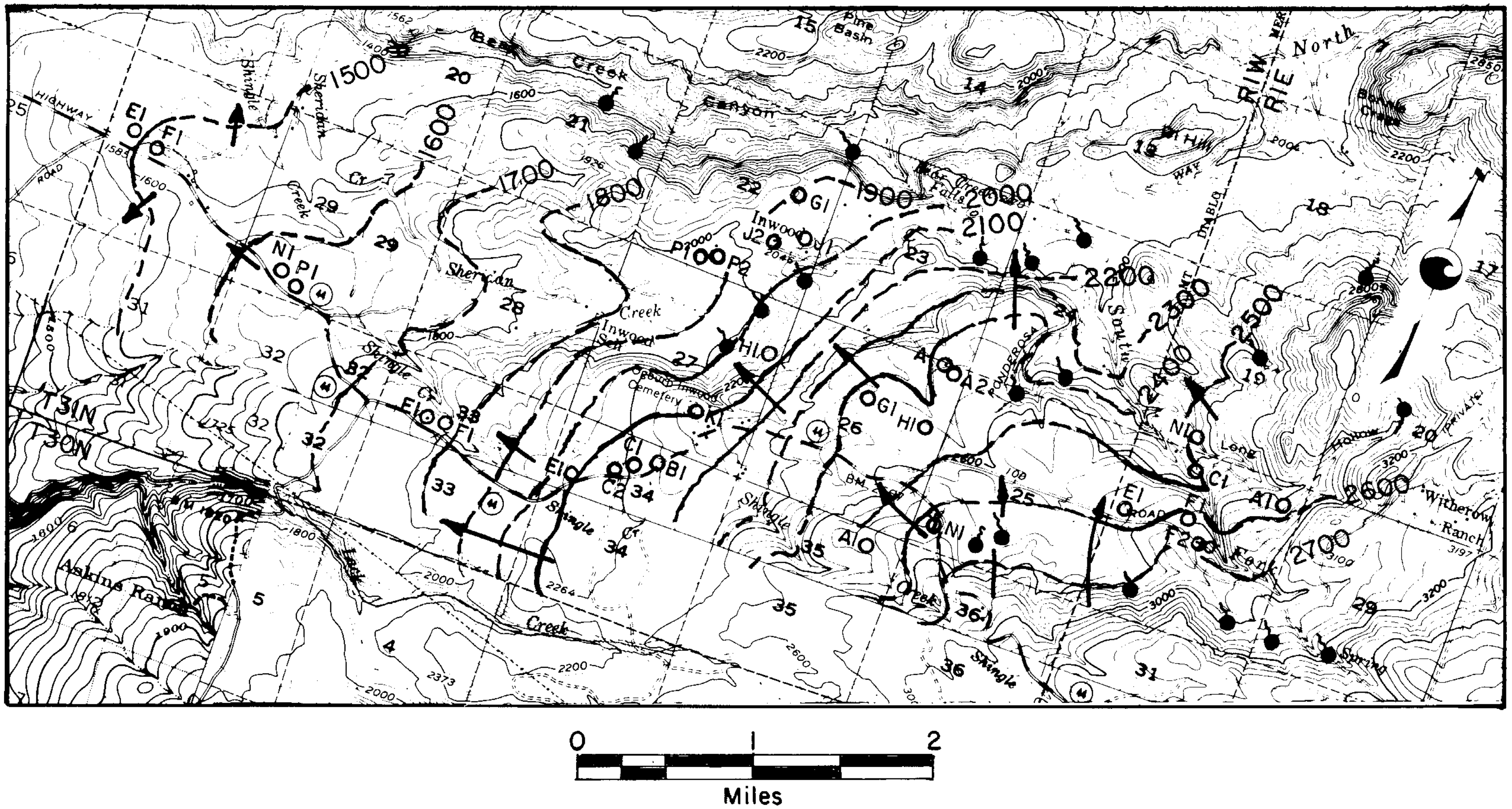
Further analysis of well drillers' reports shows that ground water is almost exclusively within the Tuscan Formation. The underlying Chico Formation, mostly fine sandstone and siltstone in the Inwood area, is virtually impermeable and yields little to no water. The overlying lava flows, though moderately porous and moderately to highly permeable, are barren of ground water because they are above the water table. The depth of the water table and the ground water gradient and flow direction are dominated by the area's topography and to a lesser extent by the distribution of the Chico Formation in the subsurface and outcrops. Figure 13 shows the generalized elevation of the water table. The ground water contours generally parallel the ground surface and therefore the water table gradient is greatest where the local terrain is steepest.

The depth to water tends to be least where the Chico Formation underlies the Tuscan at shallow depths or in areas upslope of Chico Formation outcrops. Many springs occur at the Chico/Tuscan contact, and marshy areas in broad meadows are generally underlain by the Chico Formation. These observations strongly suggest that the Chico Formation forms an effective barrier to the vertical and horizontal movement of ground water.

Monthly water-level measurements in selected wells, begun in the fall of 1979 and continued to the present, provide valuable information about the aquifer's recharge/discharge characteristics and response to precipitation. Analyses of these data and the rainfall record for the period (Figure 14) show variable recharge rates and response times in the many wells monitored. Significant generalities made are:

- Relatively shallow water levels (<100 feet) in wells show quicker response times (2 to 5 weeks) to the beginning and end of the winter rains than do the deeper (>150 feet) water levels in wells (4 to 15 weeks).
- Wells with the shallower water levels experience greater water-level fluctuations from year to year than do the wells with deep water levels.
- All wells experience a net decline in spring and fall during years of near-normal and below-normal rainfall. Conversely, a net rise in water levels occurs during years of above-normal rainfall.

The variability in response times is the result of decreasing secondary permeability and porosity with increasing depth. This and the presence of barriers to the downward movement of ground water in areas of shallow ground water account for the greater yearly water-level fluctuations.



Contour Interval 40 feet

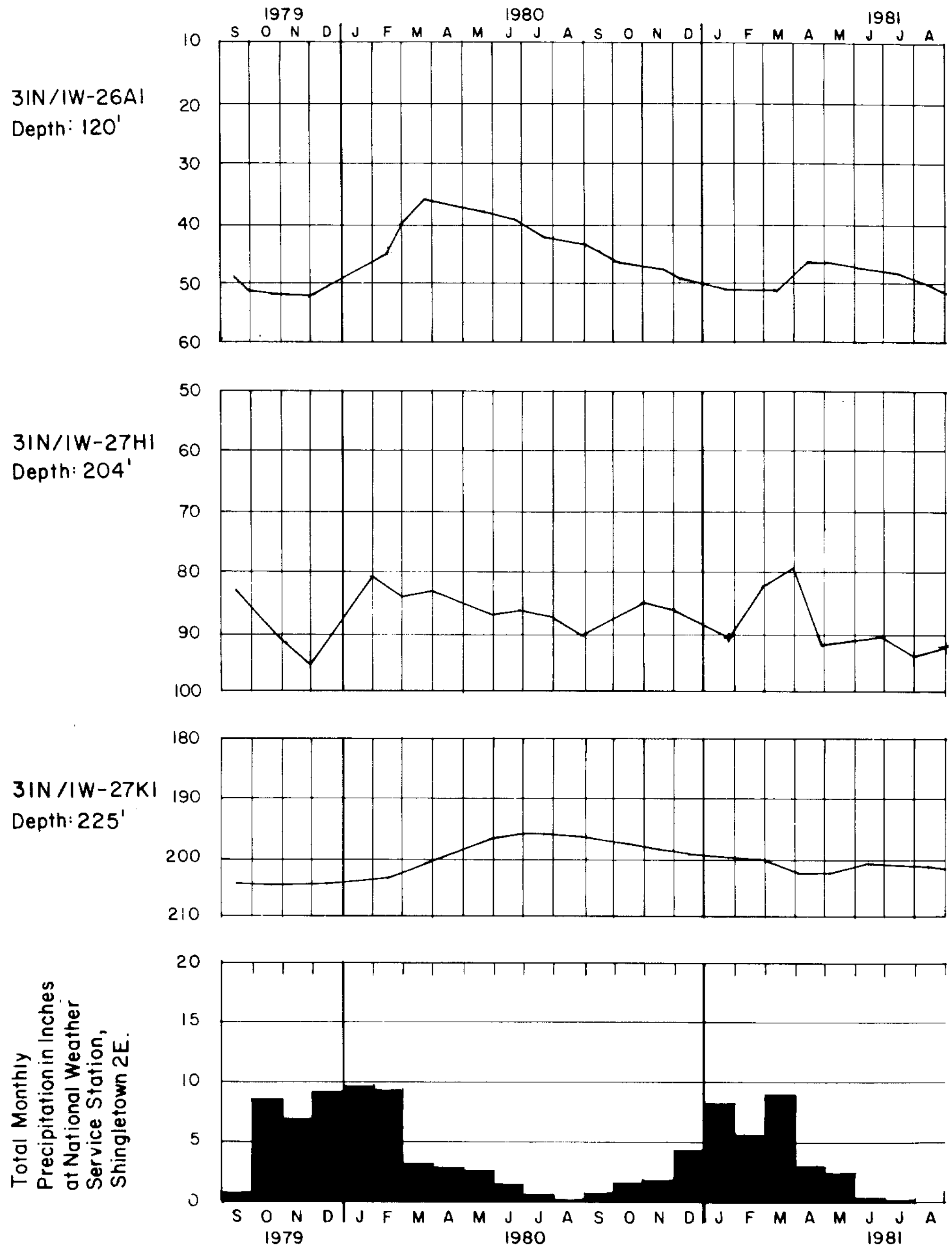
○N1 WATER LEVEL MEASUREMENT WELL

●~ SPRING

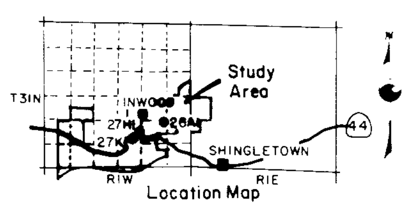
ELEVATION OF WATER IN WELLS
Dashed where inferred, arrow indicates direction of ground water movement.
Ground Water Contour Interval: 100 feet

Elevation of Ground Water in Inwood Area, Fall 1982

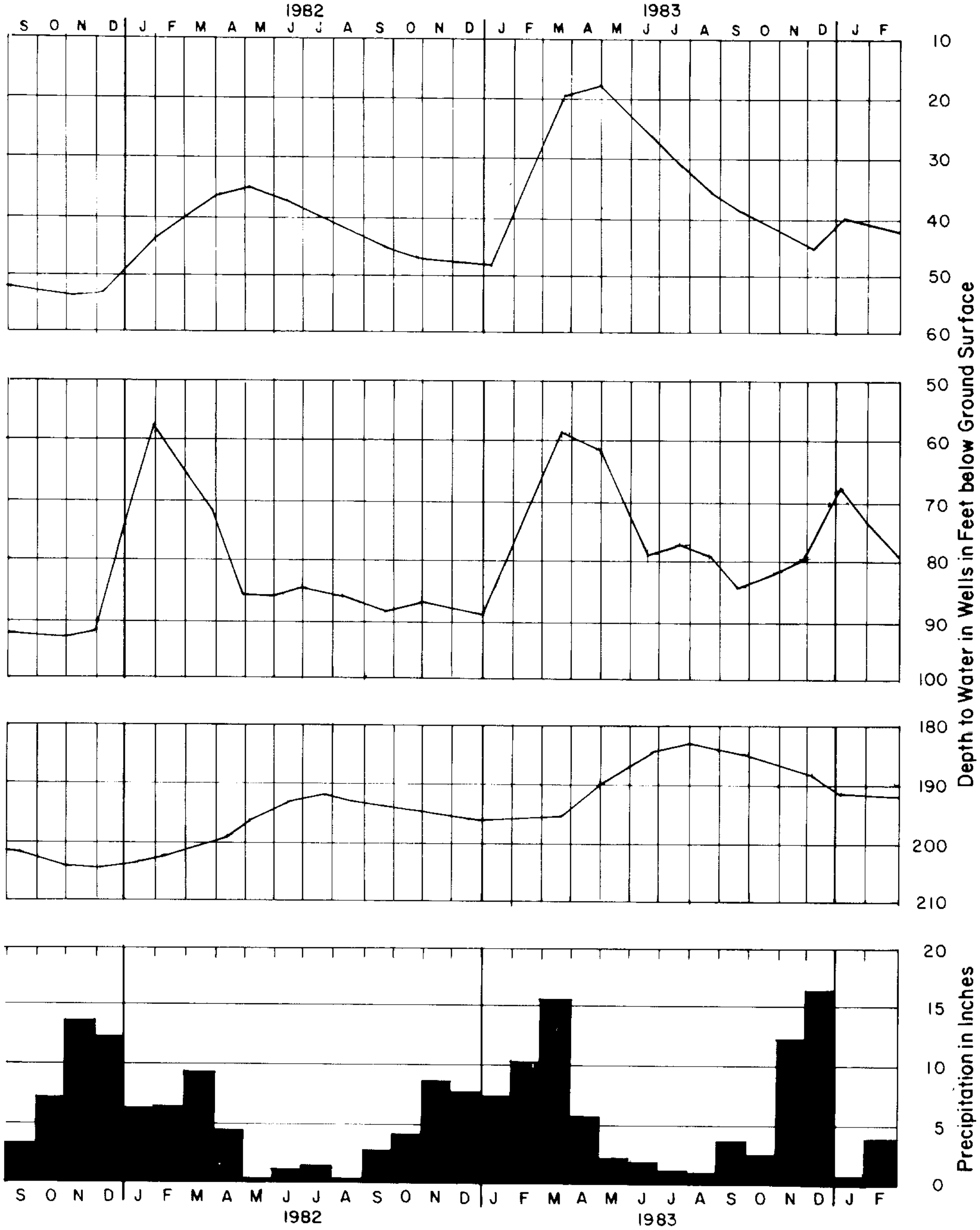
Figure 13



31N/1W-26A1
Depth: 120'
31N/1W-27H1
Depth: 204'
31N/1W-27K1
Depth: 225'
Total Monthly Precipitation in Inches at National Weather Service Station, Shingletown 2E.
1979
1980
1981
S O N D J F M A M J J A S O N D J F M A M J J A



Study Area
T31N
INWOOD
27H1
26A1
27K1
SHINGLETOWN
44
R1W
R1E
Location Map



STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

NORTHERN DISTRICT

Eastern Shasta County Ground Water Study

Hydrographs of Selected Wells, Inwood Unit

Declines or rises in water levels and their relationship to annual rainfall totals indicate that ground water surpluses occur when rainfall is above normal and deficits occur when rainfall is near normal and below normal.

Recharge of ground water is from infiltration and percolation of rainfall and surface runoff in the area underlain by the Tuscan Formation and Quaternary and Tertiary lava flows. Areas underlain by the Chico Formation accept little to no recharge due to its very low primary permeability and lack of signifiantly developed secondary permeability.

The percentage of annual rainfall available for recharge ranges from almost nothing during dry years to as much as 25 percent (18 inches) during wet years. During a normal rainfall year, deep percolation may approach 12 percent of the rainfall (about 5 inches) in some parts of the Inwood unit and as little as 2.5 percent (about 1 inch) in others. The factors that influence the amount of deep percolation are soil depth, ground slope, and the permeability of the underlying bedrock. A thick soil on gently sloping topography underlain by highly porous and permeable rock will maximize recharge. Thus, in a typical year, recharge per acre may be as much as 0.4 acre-feet/yr (360 gpd) or less than 0.08 acre-feet/yr (71 gpd). Ground water discharge is from ET, pumpage, and springs. During near-normal and below-normal rainfall years, discharge exceeds recharge, thus lowering the water table. Only during years of above normal rainfall (probably 120 percent of normal or more) will recharge exceed discharge.

Ground Water Development Potential

Based on the rainfall-recharge/discharge relationship discussed above, ground water development potential in the Inwood unit is very limited. There is adequate ground water for existing and planned development only during years of above-normal rainfall. Near-normal and below-normal rainfall years present a situation where even the existing development stresses the aquifer. Given a series of years of normal to below-normal rainfall, water levels will steadily decline. Additional ground water development would likely accelerate the decline.

The Manton Unit

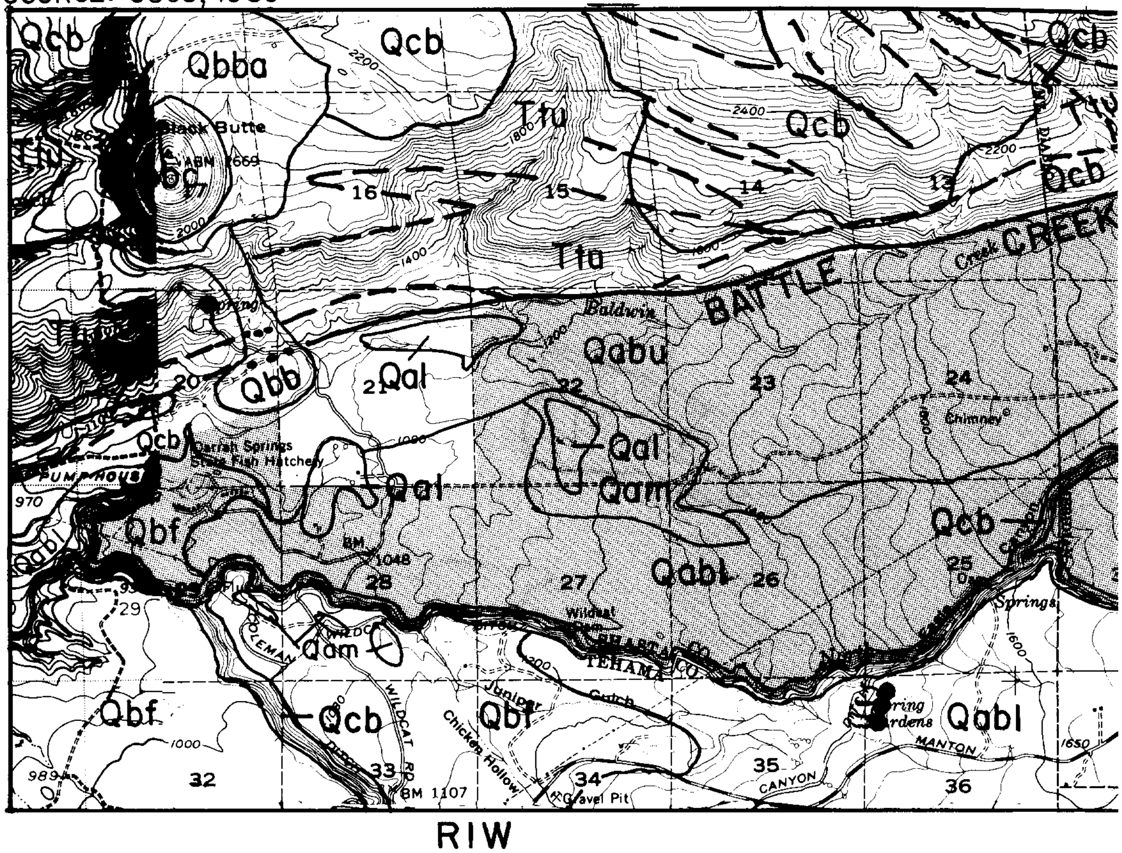
The Manton unit consists of about 9000 acres along the Shasta-Tehama County line between the Darrah Springs State fish hatchery and about three miles east of Manton (Figure 15). Elevations range from 900 feet in the west to nearly 2,800 feet to the east. Vegatative cover is mainly grasses but stands of oak and digger pine become more pronounced towards the eastern half of the unit. Existing development is concentrated almost entirely in the eastern half of the unit, near the town of Manton.

Local Geology. The Manton unit is underlain predominantly by Quaternary andesitic and basaltic pahoehoe lava flows and to a much lesser extent by Quaternary tuff breccia and alluvial fan deposits and Recent alluvium (Figure 15). The lava flows, where exposed in road cuts, are moderately to highly vesicular and exhibit crudely developed columnar structure. Vertical joint spacing ranges from 4 inches to 5 feet, while joints roughly normal to these show 1- to 3-foot spacing. The tuff breccia that underlies the extreme eastern part of the unit, a small area 1-1/2 to 2 miles east of the Darrah Springs fish hatchery, and elsewhere, is a mix of three contrasting kinds of pumice, broken blocks of tuff, and small blocks of rhyolite and andesite, all in a tuffaceous matrix (Gilbert, 1969). The alluvial fan deposits consist of round-to-subrounded gravel to boulder-sized volcanic rocks in a sandy silt matrix, and occasional lenses of sand and gravel. The deposits of Recent alluvium are unconsolidated gravel, sand, and silt, generally poorly sorted and poorly bedded.

Well drillers' reports are available for 24 wells in the Manton Unit. All but one are in the eastern third of the unit. Table 8 is a composite log that is representative of the subsurface geology. For wells in the extreme eastern part of the unit where tuff breccia occurs, 10 to 50 feet of tuff should be inserted in place of the "boulders and clay" stratum. Individual strata of lava are reported to range in thickness from 7 to 140± feet, cinder strata from 2 to 50 feet, ash strata from 4 to 50± feet, and voids from 1 to 13 feet.

The Tuscan Formation in the area south of the Battle Creek fault zone is believed to exist at about 200 feet below ground surface in the eastern half of the unit and at shallower depths westward where it begins to crop out near the Darrah Springs fish hatchery (USGS, 1980).

SOURCE: USGS, 1980



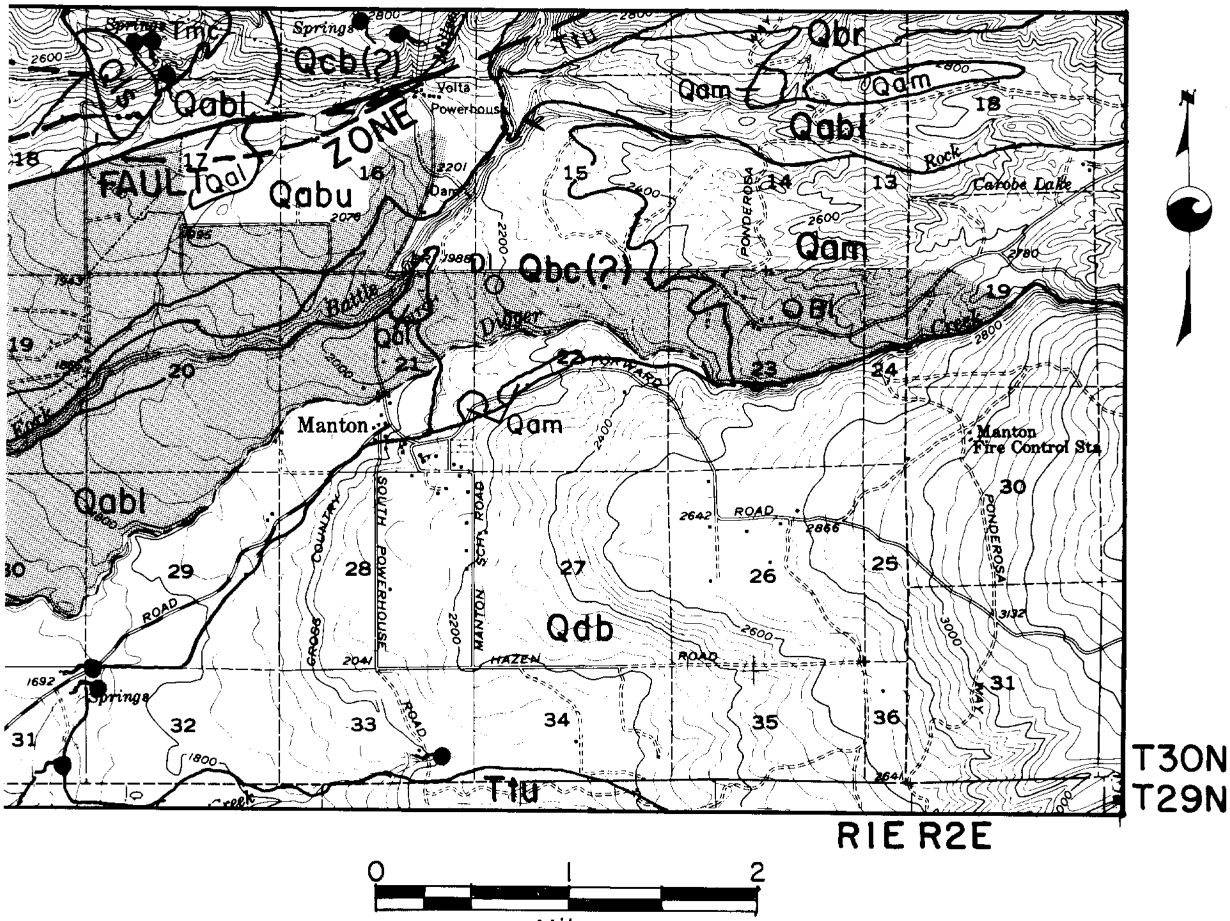
EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qls	Landslide Deposits
Qbbc	Basaltic Cinder Cone Deposits of Black Butte
Qbba	Ash of Black Butte
Qbb	Basalt of Black Butte
Qdb	Basalt of Digger Buttes
Qabu	Upper Hypersthene Andesite
Qam	Ash of Mount Maidu
Qabl	Lower Hypersthene Andesite
Qbf	Alluvial Fan Deposits of Battle Creek
Qcb	Basalt of Coleman Forebay
Qbr	Blue Ridge Rhyolite

TERTIARY

Ttu	Tuscan Formation
Tmc	Montgomery Creek Formation



Contour Interval 40 feet

O BI WATER LEVEL MEASUREMENT WELL

SPRING

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located, dotted where concealed.

STUDY AREA

Areal Geology, Manton Unit

TABLE 8

MANTON UNIT COMPOSITE WELL LOG

Depth in feet below ground surface	Drillers Call	Geologic Unit
0 - 5	Clay and rock	soil
5 - 14	Boulders and clay	weathered basalt
14 - 38	Hard lava	Pyroclastic rocks and basaltic lava flows of Quaternary age
38 - 42	Cinders and ash	
42 - 55	Fractured lava	
55 - 61	Void	
61 - 65	Fractured lava	
65 - 70	Red cinders	
70 - 106	Medium hard lava	
106 - 121	Cinders	
121 - 125	Ash	
125 - 138	Lava	
138 - 150	Cinders	
150 - 172	Fractured lava	
172 - 173	Void	
173 - 197	Fractured lava	
197 - 201	Cinders	
201 - 220	Hard lava	

Occurrence of Ground Water

In evaluating the water-yielding chacteristics of the volcanic rocks of the Manton unit, data were compiled from well drillers' reports, monthly water-well measurements of three wells, and field observations. Table 9 is a summary of data contained in the well drillers' reports.

TABLE 9

SUMMARY OF MANTON UNIT WELL LOG DATA

Yield (gmp)		Well Depth (ft)		Mean Specific
Average	Range	Average	Range	Capacity gpm/ft
20	6 to 60	222	40 to 350	1.5

The data show that the cinder strata, usually 80 to 90 feet below the ground surface, are the main water-bearing rocks in the Manton unit. In the three wells monitored, the water levels fluctuated 3 to 5 feet within a cinder zone, and on many of the well drillers' reports, cinder strata are noted as "making water" (sic). Many lava strata are reported to be "fractured" and where these occur below the water table, probably account for some of the better producing (20+ gpm) wells in the unit.

The small areas of Recent alluvium are capable of producing modest amounts (3 to 5 gpm) of shallow ground water. These alluvial deposits are at most 30 to 40 feet thick and have a relatively high specific yield (10 to 20 percent). The ground water here is perched, though, and unless the deposit is traversed by a perennial stream to provide constant recharge, they represent a minor, seasonal ground water source.

Reported water levels after well completion indicate that the Battle Creek fault zone, which roughly parallels the northern boundary of the unit, forms a barrier to ground water flow from the north. Reported water levels in wells south of the fault are well in excess of 200 feet below ground surface while water levels on the north are around 100 feet. Springs are also present at or north of the fault zone.

The slope of the water table in the Manton unit probably parallels the slope of the ground surface, generally southwesterly. Year-round recharge of ground water is probable from the many perennial streams and irrigation and power ditches in the area, though percolation of rainfall appears to be the major source of recharge. Water levels in the wells monitored here in December 1983 were higher then levels measured in November, due to recharge from late November rainfall.

The amount of recharge varies according to the amount of annual rainfall and local soil conditions. During normal rainfall years (about 30 inches), an estimated 2 inches (about 54,000 gallon per acre) go to ground water recharge in grassland areas (shallow soils); during wet years it may approach 5 inches, while during dry years there is little or no recharge. In areas of brush and trees (deeper soils) the amount of recharge from rainfall is estimated to be double that occuring in the grasslands (Appendix B).

Ground Water Development Potential

In the Manton unit, the existing ground water resources appear to be adequate for the present residential density, but the occurrence of ground water is unpredictable. The cinder strata are not continuous, and the depth to water appears to increase nearer the Battle Creek fault zone. Two wells of similar depth and construction, 100 yards apart, can show dissimilar subsurface rock strata and water yields—one may yield up to 40 gpm while the other yields nothing.

Areas mapped as Recent alluvium in Figure 15 are considered to have a limited shallow ground water development potential due to the relative thinness and limited area of the deposits. The majority of the area, mapped as Quaternary lava flows, has a moderate-to-good development potential, but because the availability of ground water, its depth and the well yield it will provide are unpredictable, the water resources should be proven before there is future development. The development potential of the areas mapped as tuff breccia is the same as the Quaternary lava flows in that ground water occurs in this area beneath the cover of the tuff.

Oak Run Unit

The Oak Run unit consists of about 5,200 acres in five separate parcels located from just north of Millville, northeast to Oak Run (Figure 16). The area ranges in elevation from about 500 feet to 1,700 feet and is characterized by broad, gentle uplands dissected by streamcut valleys. The uplands are generally covered by grasslands, while valley sides and bottom lands support growths of brush, oak, and pine. Oak Run Road, the main transportation corridor, links with State Route 44 to the southwest and Highway 299E to the north.

Local Geology

The Oak Run unit lies mainly within the Great Valley and Cascade Range geomorphic provinces. Rocks of the Klamath Mountains province are also present where the overlying volcanic and sedimentary rocks have been eroded away.

The geologically oldest rocks in the unit are Triassic metavolcanic rocks of the Bully Hill Rhyolite. They are exposed generally north and west of Oak Run and are unconformably overlain by both the Chico and Tuscan Formations.

The Cretaceous Chico Formation underlies much of the valley bottom lands. It is chiefly shale but also contains beds and lenses of sandstone and conglomerate. It dips gently to the west and southwest and is unconformably overlain by the Tuscan Formation and locally by Pleistocene alluvial fan deposits and Recent alluvium.

The Tuscan Formation underlies most of the unit and consists of lava flows, tuff breccia, tuff, and semi-consolidated sand, gravel, and clay. Well drillers' reports show the lava flow and tuff breccia are the main components of the Tuscan Formation in the eastern half of the unit. The semi-consolidated sand, gravel, and clay become dominant in the west half of the unit.

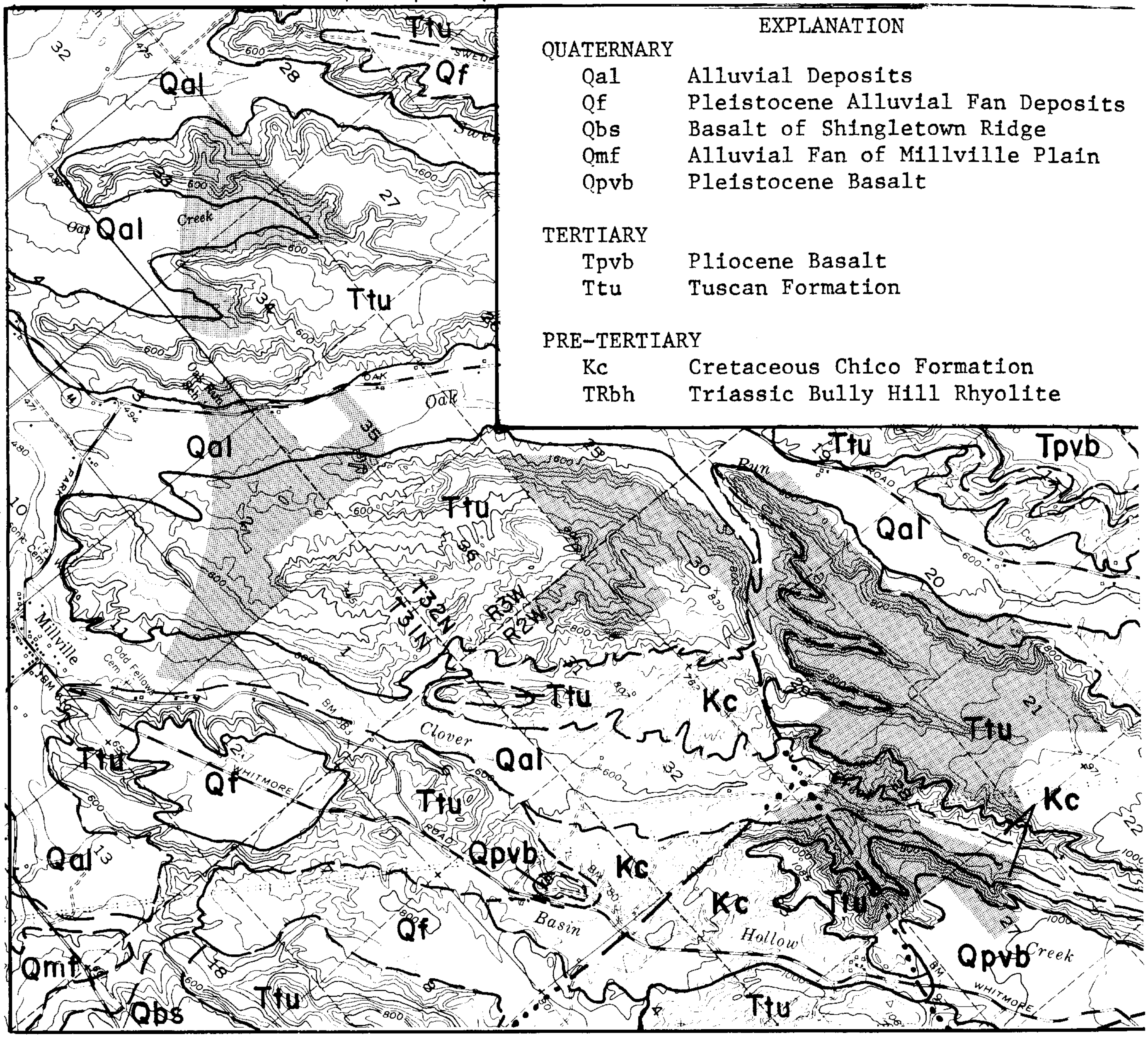
East and north of Millville are thin Pleistocene alluvial fan deposits. These locally overlie the Tuscan and Chico Formations and are equivalent to the Red Bluff Formation, widespread to the west and southwest.

Recent alluvium--clay to boulder-size material--locally overlies all of the older rocks in the unit, with the exception of the Pleistocene alluvial fan deposits. It ranges in thickness from less than a foot to probably not more than 10 or 20 feet.

Occurrence of Ground Water

In evaluating the occurrence of ground water in the Oak Run unit, 62 well drillers' reports were reviewed and water levels in three wells were measured monthly. A summary of well depths, yields, and specific capacities for the 62 reports is shown in Table 10.

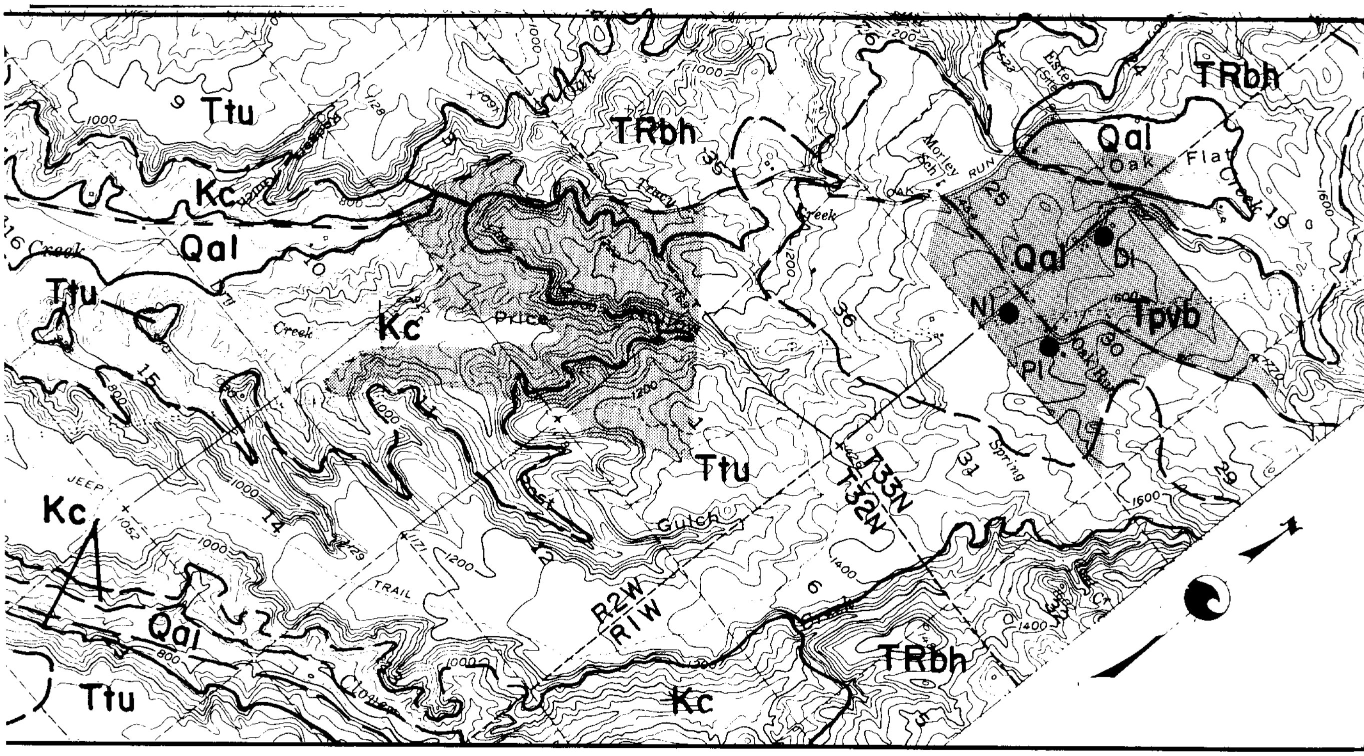
SOURCE: Modified from USGS, 1980; DWR, 1958



● D1 WATER LEVEL MEASUREMENT WELL

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located, dotted where concealed.



0 1 2
Miles

Contour Interval 40 feet

STUDY AREA

Areal Geology, Oak Run Unit

TABLE 10

SUMMARY OF OAK RUN UNIT WELL REPORT DATA

Well Depth (ft)		Yield (gpm)		Specific Capacity[1]	
Average	Range	Average	Range	Average	Range (gpm/ft)
128	60-314	33.3	1-100	2.4	0.01-8.6

Wells completed in the Tuscan Formation are the most productive. Of the Tuscan Formation wells, those in the semi-consolidated sediments generally have higher yields, from shallower depths, than those in the tuff breccia and lava flows. The deepest and lowest yielding wells are generally those completed mainly in the Chico Formation.

Recharge is mainly from precipitation and is greatest in the areas covered with brush and woodlands (Appendix B). Below about the 700-foot elevation of the main southwestward-flowing streams, infiltration of streamflow contributes to aquifer recharge.

Recharge rates vary with annual rainfall totals and range from almost none during dry years to 6 to 14 inches during wet years. For normal rainfall years (36 to 44 inches), 1 to 5 inches of deep percolation[2] can be expected in the brush and woodland areas and zero to 3 inches in the grassland areas of the unit (Appendix B). Around the town of Oak Run, recharge from surface irrigation is locally significant and potentially adds 6 to 8 inches of recharge to aquifers overlain by irrigated lands. In this area, three water-level monitoring wells for this study were measured in 1956 and 1957 by DWR. These data show that the water table is now at, or slightly higher than, its level nearly 30 years ago.

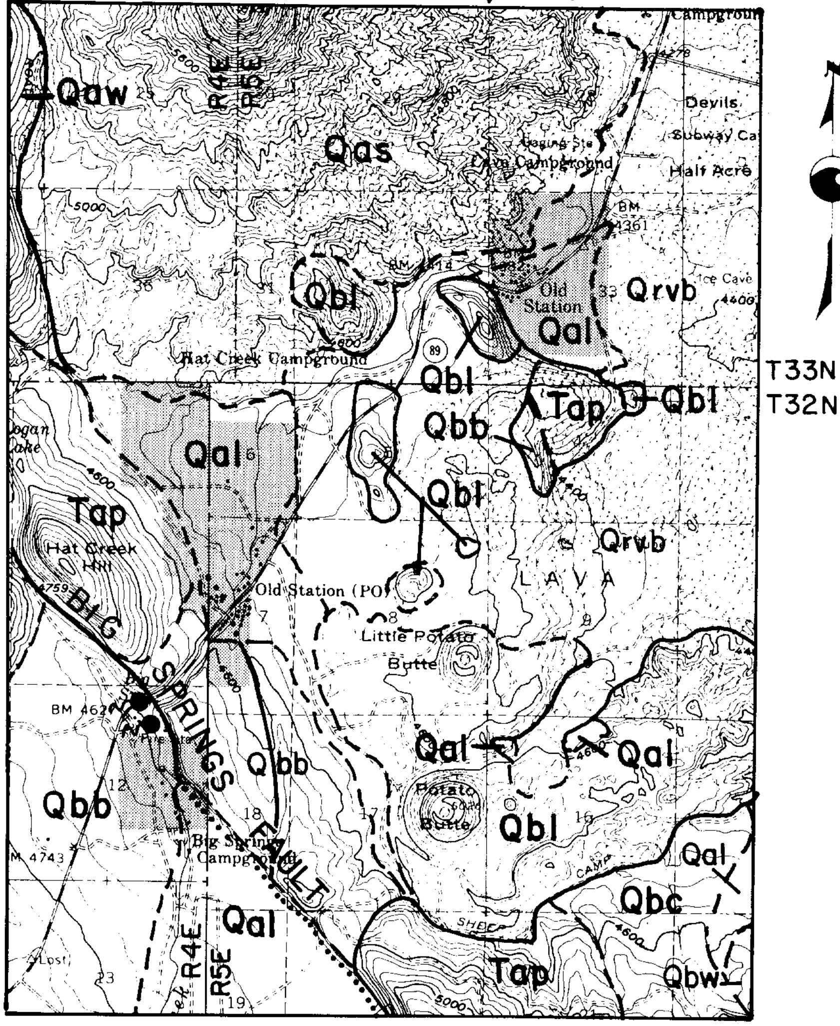
Ground water flow is generally southwesterly. Above the 700-foot elevation, local topography may strongly influence flow directions, with flow moving from highs to lows and contributing to the base flow of the area's streams.

1/ Based on 18 well reports with both yield and drawdown data

2/ One inch of deep percolation is equivalent to about 27,000 gallons of recharge per acre of land.

SOURCE: Modified from USGS, 1963

Figure 17



0 1 2

Miles

Contour Interval 40 feet

EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qrvb	Recent Basalt
Qas	Andesite of Sugarloaf Peak
Qbl	Pleistocene Basaltic Andesite
Qbc	Basalt of Badger Flat
Qbw	Basalt of West Prospect Peak
Qaw	Andesite of Wilcox Peak
Qbb	Burney Basalt

TERTIARY

Tap	Pliocene Pyroxene Andesite

SPRING

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located, dotted where concealed.

STUDY AREA

Areal Geology, Old Station Unit

In the area of Big Springs, on the southwest side of a dominant northwest-trending fault, hereafter referred to as the Big Springs fault, well drillers' report show subsurface geology very similar to that found at the two campground wells northeast of the fault.

Occurrence of Ground Water

Within the Old Station unit, only the area south of the Big Springs fault has a developed ground water resource. The areas north of the fault are served by distribution systems drawing surface water from Hat Creek. There are two different water sources in the unit, due to the Big Springs fault. The fault is a barrier to ground water flow. Ground water is "dammed up" on its south side, and Big Springs, at the lowest point along the fault, is at the "dam's spillway". North of the fault, the underlying lava flows are fractured and extremely porous; water entering from the ground surface percolates easily, quickly, and to a great depth (800-1,000 feet[1/]) and then flows northward to reappear in springs at Rising River. Lacking a mechanism to impede the movement of ground water in this area, such as a fault, ground water exits the area very quickly.

Ground water recharge for the area south of the Big Springs fault is from rainfall, streamflow, and snowmelt runoff occurring within the upper Hat Creek watershed. The rate of recharge can be estimated by assuming that the discharge of Big Springs (about 380 gpm) is approximately equal to the recharge occurring in the upper watershed. Thus, about 1.7 acre-feet per day (540,000 gpd) is estimated. The actual volume of recharge will be somewhat greater due to consumptive use and gains to Hat Creek in the general area of Big Springs. Nevertheless, a substantial volume of ground water is both discharged and recharged on a daily basis.

Ground Water Development Potential

As previously mentioned, the area north of the Big Springs fault is dependent upon surface water for its supply. Ground water here may be developed, but the depth to water and the uncertainty of maintaining a reliable source make development tenuous and a risky capital investment. The area south of the fault, however, has an abundant ground water resource and the development potential, based on this resource, is almost unlimited. The potential for ground water contamination via septic systems should be the overriding consideration in future development here.

1/Based on the elevation and gradient of the water table in the Hat Creek Unit.

Salt Creek Unit

The Salt Creek unit is 1 to 4 miles east and northeast of Bella Vista and consists of about 2,200 acres (Figure 18). The area has low-to-moderate topographic relief characterized by broad, flat bottomlands and low, rounded hills. Vegetative cover is predominantly grasses with locally dense brush and woodlands.

Local Geology

The northern boundary of the Salt Creek unit is defined by the surface exposure of the contact between the Cretaceous Chico Formation and the Triassic Pit Formation. This contact is an erosional unconformity. In the Salt Creek unit, the Chico ranges in thickness from zero at the surface exposure of the contact to an estimated 1,500 feet beneath the southern-most portion of the unit. From well logs and engineering reports (DWR, 1958), the Chico primarily consists of impermeable to slightly permeable interbedded shales and sandstones.

Overlying the Chico in the southern portion of the unit is the Tuscan Formation and a thin veneer of alluvial materials in and along stream channels.

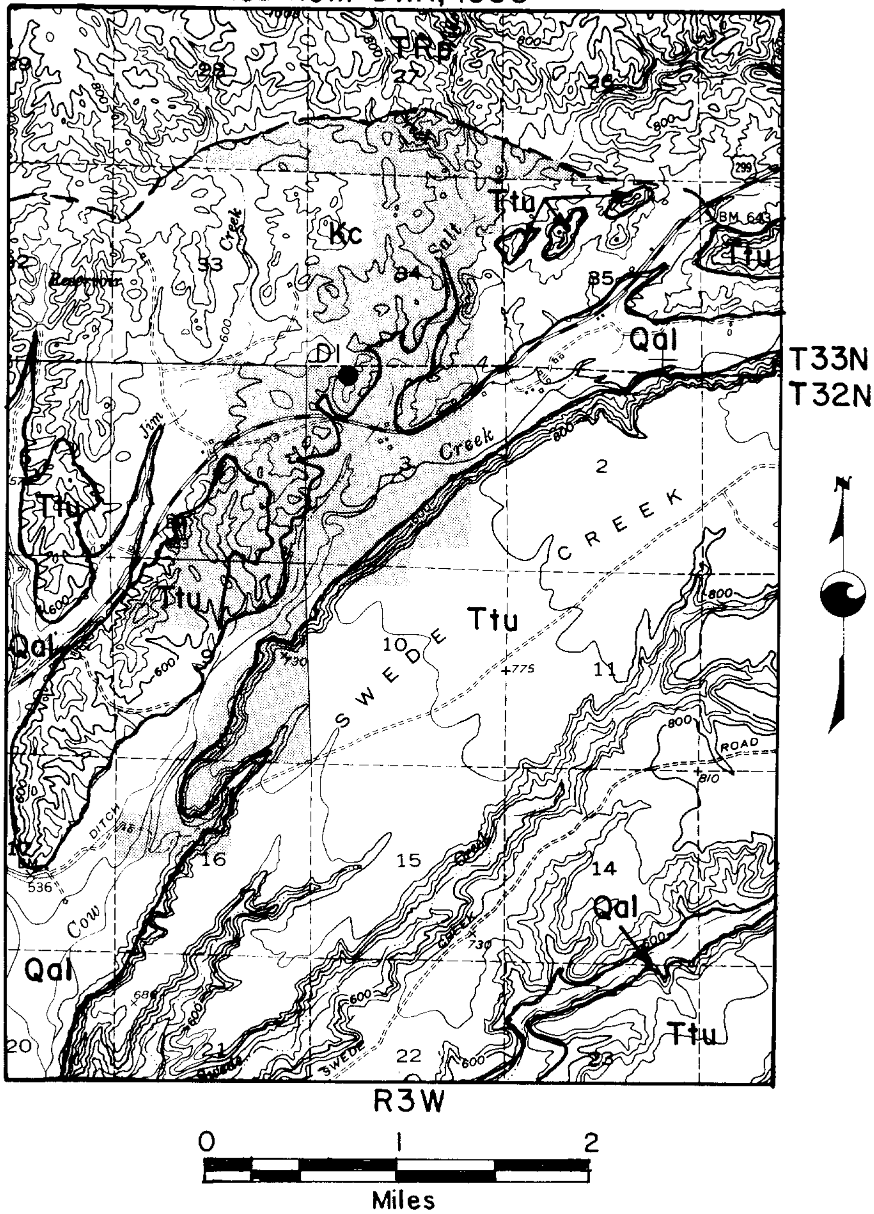
The Tuscan Formation in this area consists of semi-consolidated clay and clayey gravel and is locally capped by a 5- to 20-foot section of andesite mudflow breccia. South of Little Cow Creek in Sec. 10, T32N/R3W, MDB&M, the Tuscan approaches 200 feet in thickness and thins southwesterly to less than 25 feet near the Dry Creek-Little Cow Creek confluence (DWR, 1958). Alluvial material, unconsolidated sand, gravel, cobbles and boulders mantle the Chico Formation in stream channels and floodways. It is usually only a foot or so thick but may be as much as 10 to 15 feet thick in places.

Occurrence of Ground Water

The occurrence of ground water in the Salt Creek unit is very limited. The Chico Formation, which underlies the area or is found at depth below younger geologic units, has very low primary and secondary permeabilities. Wells drilled in Chico rarely yield more than 4 to 5 gallons per minute and many are reported dry; specific capacities for producing wells range from 0.3 to less than 0.1 gallons per minute per foot drawdown. Saline, connate water is also present in the Chico Formation.

SOURCE: Modified from DWR, 1958

Figure 18



Contour Interval 40 feet

EXPLANATION

● DI WATER LEVEL MEASUREMENT WELL

QUATERNARY
Qal Alluvial Deposits

TERTIARY
Ttu Tuscan Formation

PRE-TERTIARY
Kc Cretaceous Chico Formation
TRp Triassic Pit Formation

CONTACT
Dashed where approximately located.

STUDY AREA

Areal Geology, Salt Creek Unit

Wells completed in the Tuscan Formation fare better than those in the Chico. Yields of 4 to 15 gpm are common and specific capacities usually range between 1 and 4 gpm/ft.

A few wells in the northern portion of the unit have been drilled through the Chico into the underlying Pit Formation[1/]. Based on these and the findings for the Eastern Klamath Mountains unit to the north and east, such a well completion will encounter highly variable water prospects ranging from dry holes to well yields in excess of 20 gpm. When ground water is encountered in the underlying Pit Formation, it is likely to be confined.

Ground Water Development Potential

The ground water development potential for the Salt Creek unit ranges from poor to moderate, depending on the geologic formation one taps. Within a quarter of a mile of the northern unit boundary, wells can be completed in the Pit Formation and may yield adequate ground water for future developments. In the southern one-third of the unit, in areas underlain by the Tuscan Formation, ground water sufficient for existing and future development may be available.

Shingletown Unit

The Shingletown unit consists of about 5,800 acres along State Route 44 from 1-1/2 miles west to 6 miles east of Shingletown (Figure 19). The area has dense forests of fir and cedar, and local topography of low relief. The many springs that occur in and around to the unit hint at the abundance of the underlying ground water resource.

Local Geology

The Shingletown unit is on a broad flow of Quaternary olivine basalt that extends for nearly 30 miles from the vicinity of Red Lake Mountain, about 6 miles northeast of Viola, west nearly to Millville. Small, relatively thin deposits of Recent alluvium occur within the unit and are shown in Figure 19.

Well drillers' reports for 64 wells in the unit show a diversity of rock types in the subsurface that reflects the area's geologic past. The eastern half of the unit, being nearer the eruptive centers of the southern Cascades, is dominated by lavaflows and cinder and ash strata. Further west,

1/ See the discussion of the "Eastern Klamath Mountains Unit".

mudflow breccia is noted more frequently in the drillers' reports. Just west of Shingletown, some wells penetrate the underlying Cretaceous Chico or Eocene Montgomery Creek Formations at depth.

Table 11 is a composite well log of the Shingletown unit's wells. Though the subsurface geology is variable, changing from east to west, it is representative of the general area. Individual strata of lava are reported to range in thickness from 5 to 90 feet, cinders from 3 to 40 feet, ash from 2 to 50 feet, mudflow breccia from 2 to 47 feet, and sand and gravel from 2 to 20 feet.

Occurrence of Ground Water

In evaluating the water yielding characteristics of the volcanic rocks of the Shingletown unit, data were compiled from water well drillers' reports, monthly water level measurements of four wells, and field observations. Table 12 is a summary of data contained in 64 well drillers' reports of wells in the unit.

TABLE 11

SHINGLETOWN COMPOSITE WELL LOG

Depth in Feet Below Ground Surface	Drillers Call	Geologic Unit
0 - 3	Red clay	Soil
3 - 10	Red clay and boulder	Weathered basalt
10 - 26	Brown lava rock	Quaternary basalt
26 - 30	Black cinders and ash	Tuscan formation
30 - 51	Fractured lava rock	
51 - 60	Volcanic mudflow	
60 - 86	Reddish-brown lava rock	
86 - 89	Sand and gravel	
89 -103	Red cinders	
103 -130	Fractured lava rock	

EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qpvb	Pleistocene Basalt
Qpva	Pleistocene Andesite

TERTIARY

Tva	Pliocene Andesite
Ttu	Pliocene Tuscan Formation
Tmc	Montgomery Creek Formation

PRE-TERTIARY

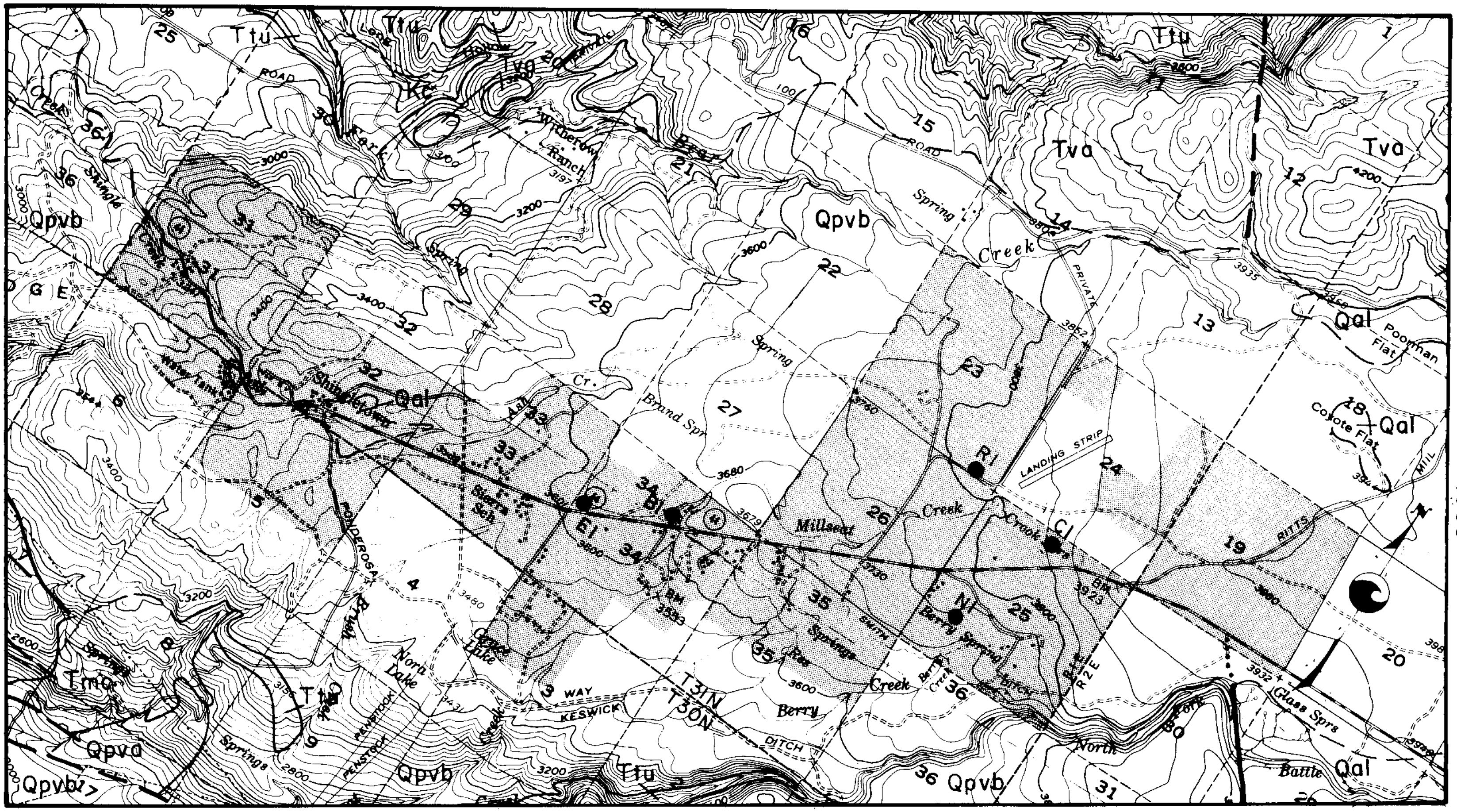
Kc	Cretaceous Chico Formation

● E1 WATER LEVEL MEASUREMENT WELL

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located,
Dotted where concealed.

STUDY AREA



SOURCE: Modified from USGS 1972 and 1980

0 1 2

Miles

Contour Interval 40 feet

Areal Geology, Shingletown Unit

Figure 19

TABLE 12

SUMMARY OF SHINGLETOWN UNIT WELL LOG DATA

Yield (gpm)		Well Depth (ft)		Mean Specific
Average	Range	Average	Range	Capacity (gpm/ft)
34	4-275	131	50-280	11.6

The data indicate that the lava strata, particularly those below 50 to 100 feet of the ground surface, are the main water-producing strata of the unit. The mudflow breccia strata are aquicludes, and, when encountered at shallow depths perch water and at depth may confine water. The ash, cinder, sand and gravel strata, though generally permeable and porous, are minor elements in the subsurface and are considered minor aquifers.

Recharge of ground water in the Shingletown unit occurs year-round from infiltration and percolation of streamflow and precipitation; it is greatest in winter and spring. This is apparent in wells that "blow" air. It is theorized that air in the intermediate vadose zone is trapped between the soil-water zone above and the water table below. As water percolates from the upper zone, the air is displaced and exits the subsurface via wells that are perforated above the water table. Some wells produce light blows in the summer and fall and heavier ones after the onset of the winter rains.

It is estimated (Appendix B) that during years of normal rainfall, recharge approaches 11 inches (about 300,000 gallons per acre). During very wet years, recharge may be more than double this. In dry years recharge from rainfall may be nil through streamflow may account for a small, undetermined, amount.

Ground water discharge in the unit, other than from pumping and ET, occurs from springs and from subsurface through flow to beyond the unit, generally in a downslope direction.

Ground Water Development Potential

The occurrence and availability of ground water tend to decrease east to west in the Shingletown unit according to well drillers' reports. Probably because of the subsurface distribution of the mudflow tuff breccia mentioned above, depths to water increase and yields decrease from east to west.

However, this trend has little effect on development potential because even the relatively low yielding wells (4 to 10 gpm) produce enough water for domestic needs. Any constraints on development should be based on potential ground water contamination from septic tanks and leach fields. Open joints and fractures provide ready access of surface waters to the ground water.

Viola Unit

The Viola unit consists of about 680 acres about 12 miles east of Shingletown on State Route 44 (Figure 20). Bailey and Deer Creeks, tributaries to North Fork Battle Creek, flow across the unit. Many springs occur in the area that contribute to the base flow of the streams.

Local Geology

The Viola unit is near the crest of the Cascade Range and is underlain by a variety of volcanic rocks and Recent alluvium. At the surface, the volcanic rocks are pyroxene and basaltic andesite and dacite flows of Pliocene and Pleistocene age. The alluvium consists of a mixture of clay-to-cobble size material deposited by streams.

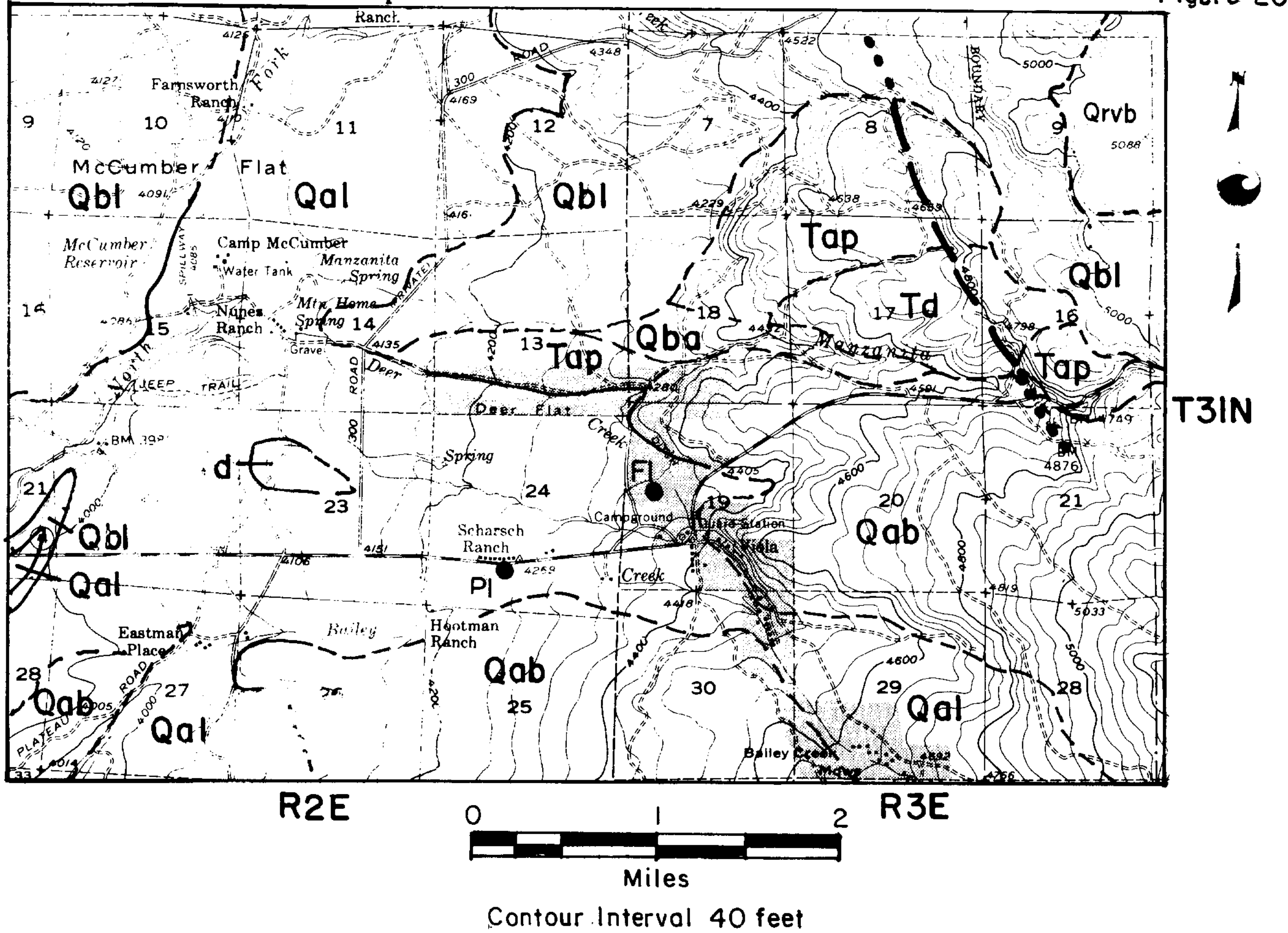
Water well drillers' reports for 14 wells in and around the Viola unit show a fairly uniform stratification of alluvium and volcanic rocks. This is shown in Table 13, a generalization of the 14 well logs. This composite log shows that the alluvium is about 32 feet thick and overlies a succession of volcanic rocks at depth. These volcanic rocks are composed of two 10 to 40-foot thick "lava" flows, presumably the Quaternary andesite separated by a 40- to 80-foot section of sand, gravel, ash, and cinders.

Occurrence of Ground Water. In evaluating the water-yielding characteristics of the volcanic rocks and alluvium of the Viola unit, data were compiled from well drillers' reports, monthly water level measurement of two wells, and field observations. Table 14 is a summary of data contained in the well drillers' reports.

The data indicate that the interbedded sand-gravel-ash-cinder strata within the basaltic andesite is the primary aquifer of the Viola unit. The seasonal fluctuation of the water table in these strata is only about one foot. The available data are not conclusive, but they suggest that the ground water in the alluvium is perched in some or all of the unit and that the "lava"

SOURCE: Modified from USGS, 1963

Figure 20



EXPLANATION

QUATERNARY

Qal	Alluvial Deposits
Qrvb	Recent Basalt
Qbl	Pleistocene Basaltic Andesite
Qab	Andesite of Brokeoff Mountain
Qba	Lower Pleistocene Basaltic Andesite

TERTIARY

Td	Pliocene Dacite
Tap	Pliocene Pyroxene Andesite

● Pl WATER LEVEL MEASUREMENT WELL

CONTACT
Dashed where approximately located.

FAULT
Dashed where approximately located, dotted where concealed.

STUDY AREA

Areal Geology, Viola Unit

TABLE 13

VIOLA UNIT COMPOSITE WELL LOG

Depth in feet below ground surface	Drillers Call	Geologic Unit
0 - 6	Gravelly clay	Soil
6 - 35	Sandy clay with cobbles	Recent alluvium
35 - 58	Hard lava rock	Quaternary andesitic Basalt
58 - 84	Sand, gravel, and ash	Pyroclastic rocks and alluvial deposits, probably Tuscan formation
84 - 92	Black cinders	
92 - 100	Sand, gravel, and ash	
100 - 107	Black cinders	
107 - 116	Sand and ash	
116 - 122	Red cinders	
122 - 140	Hard lava	Quaternary andesitic Basalt

TABLE 14

SUMMARY OF VIOLA UNIT WELL LOG DATA

Yield (gpm)		Well Depth (ft)		Mean Specific
Average	Range	Average	Range	Capacity (gpm/ft)
20	8 to 40	133	58 to 263	1.3

strata in some wells contribute significantly to the reported yields.

Recharge and discharge of ground water in the Viola Unit appears to be relatively balanced through time with the lowest water table elevations corresponding to times of maximum ET. The water table rises in the fall, even before any appreciable precipitation has occurred, in response to the cooler temperatures and decreasing ET.

The springs, generally west of the unit, and Deer Flat, in the northern portion of the unit, represent areas of ground water discharge.

Movement of ground water in both the alluvial and sand-cinder strata is probably westerly. Recharge of the alluvial stratum is most likely from percolation of streamflow and precipitation. Because the streams are perennial, recharge occurs year-round and probably accounts for the minor fluctuations of the water table. It is likely that only a very small percentage of the precipitation falling on the unit adds to the recharge of the alluvium, due to a lack of available storage space. Because the sand-cinder stratum is concealed beneath the alluvium and a lava flow and is not observed to crop out in the vicinity, it is presumed that some of the rainfall on and streamflow across the surface exposures of the lava flows to the north and east finds its way to this stratum via fractures in these rocks.

Ground Water Development Potential. The Viola unit and surrounding area appears to have sufficent ground water for the existing development. Average well yields of 20 gpm, accompanied by modest drawdowns and an apparent absence of significant change in ground water storage, suggest that this area has potential for additional development.

Areas mapped as Recent alluvium on Figure 20 are considered to have good development potential, though care should be taken in well and septic system spacing. Areas mapped as Pliocene and Pleistocene volcanic rocks have moderate to good development potential; but due to the variable occurrence of ground water from these rocks, the water resource should be proven before any development proceeds.

Whitmore Unit

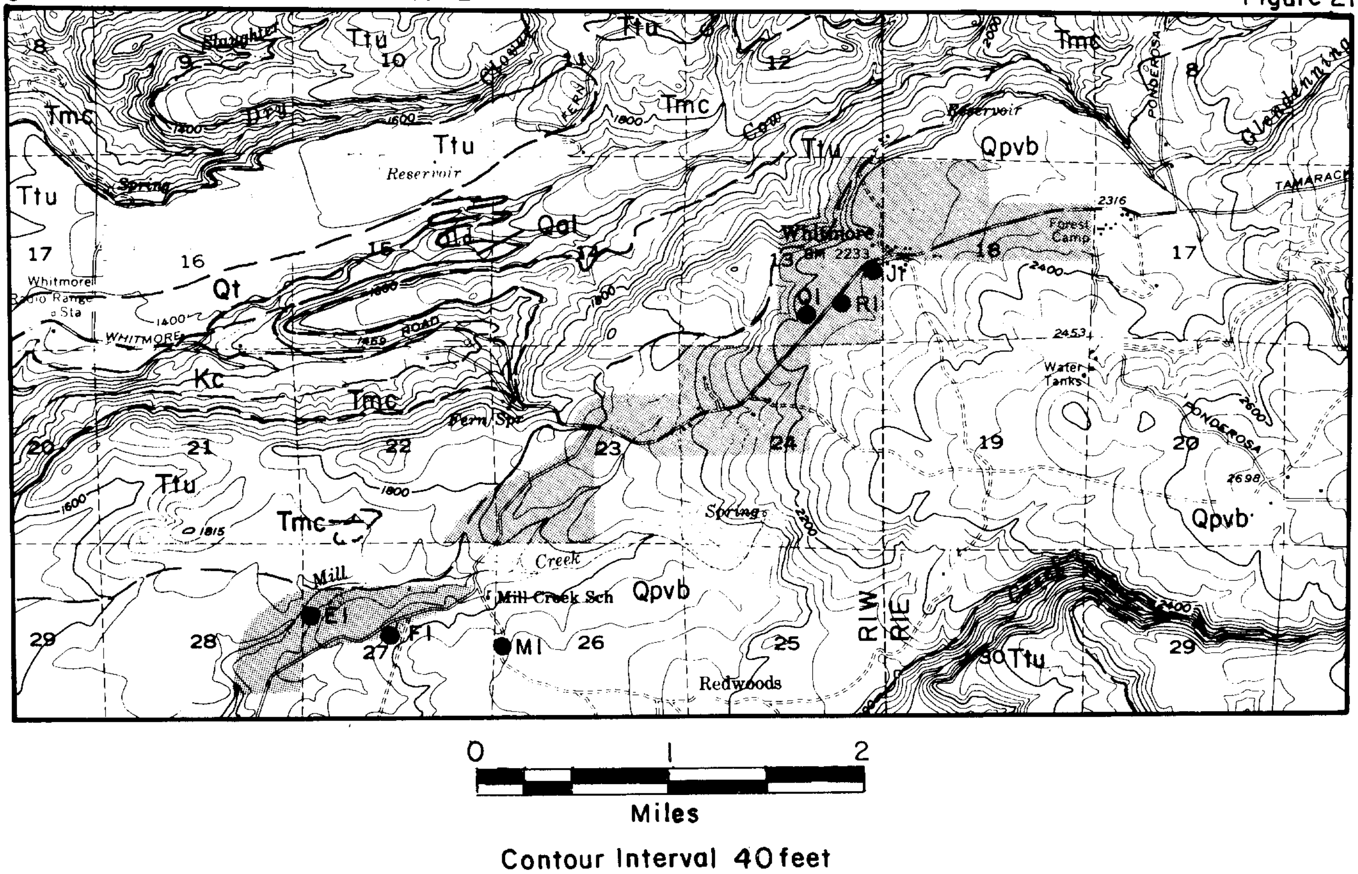
The Whitmore unit is along the drainage divide between Old Cow Creek and South Cow Creek between 1,600 and 2,300 feet elevation (Figure 21). It consists of about 1,200 acres and is covered almost exclusively with brush and mixed forest of hardwoods and fir and pine. The area is relatively densely populated with most of the existing development centered along Whitmore Road.

Local Geology

The Whitmore unit is underlain almost entirely by a Quaternary olivine basalt flow. The flow is believed to have originated in the headwater region of Glendenning Creek and covers an area of over 25 square miles (MacDonald, 1972).

SOURCE: Modified from USGS 1972

Figure 21



EXPLANATION

QUATERNARY

Qal	Recent Alluvial Deposits
Qt	Quaternary Terrace Deposits
Qpvb	Pleistocene Basalt

TERTIARY

Ttu	Tuscan Formation
Tmc	Montgomery Creek Formation
Kc	Cretaceous Chico Formation

● Rl WATER LEVEL MEASUREMENT WELL

CONTACT
Dashed where approximately located.

STUDY AREA

Areal Geology, Whitmore Unit

This flow is highly weathered and is shown on well drillers' reports to consist of mostly clay and boulders. Its estimated thickness is 50 to 200 feet though its true thickness is unknown due to its similar lithologic character with the underlying Tuscan Formation.

Underlying the Quaternary basalt flow is the Tuscan Formation. It is mainly interbedded lava flows and pyroclastic deposits. The lava flows are mainly andesites and the pyroclastic rocks are beds of tuff and cinders. The Tuscan Formation here is estimated to obtain a maximum thickness of about 300 feet.

To the north and northwest of the unit, Old Cow Creek has eroded it valley to below the base of the Tuscan Formation to locally expose the Eocene Montgomery Creek and Cretaceous Chico Formations. These formations are lithologically similar, consisting of silty sandstone and shale, and usually can only be differentiated by the examination of fossil evidence.

Terrace deposits, similar in nature to alluvium, lie above the present stream level of Old Cow Creek west of Whitmore. These consist of gravel and cobble size material in a matrix of sand and silt.

Occurrence of Ground Water

In evaluating the occurrence of ground water in the Whitmore unit, 36 well drillers' reports were reviewed and monthly water level measurements were made in six wells. Yield, well depth, and specific capacity data from the reports are summarized in Table 5.

TABLE 5

SUMMARY OF THE WHITMORE UNIT WELL LOG DATA

Yield (gpm)		Well Depth (ft)		Specific Capacity (gpm/ft)1/	
Average	Range	Average	Range	Average	Range
21	7 to 50	183	69 to 427	0.9	0.1 to 1.5

The primary aquifer in the unit is comprised of the Tuscan Formation which overlies the Eocene and Cretaceous sedimentary rocks. It contains free ground water which locally may be perched. Perched water may also by encountered near the base of the Quaternaty basalt flow.

1/ Based on 18 well reports with both yield and drawn data for wells completed in the Tertiary and Quaterary volcanic rocks.

The Montgomery Creek and Chico Formations, which unconformably underlie the Tuscan Formation, are only slightly permeable and thus form a barrier to the downward movement of ground water. This is evidenced by the occurrence of springs and seeps at their contact with the Tuscan Formation. However, a few wells in the unit do pump from these and are reported to produce modest amounts of water.

Recharge is mainly from infiltration of rainfall. During a normal rainfall year (about 44 inches) 9 inches of deep percolation are estimated (Appendix B). For dry years, recharge is limited to almost nothing while during wet years it may approach 39 inches.

The aquifer in the part of the unit in Sections 27 and 28, T32N/1W is partially recharged from streamflow in Mill Creek. Water levels measured in three wells here remain relatively static and at elevations slightly less than the creek.

Ground water discharge, other than from pumping and ET, is from through-flow and, as mentioned above, seeps and springs at the base of the Tuscan Formation.

Ground Water Development Potential

The ground water development potential of the Whitmore unit appears to be poor-to-moderate. The area's geologic setting is remarkably similar to the Inwood area which has a poor ground water development potential due to its local geology and present land use practices. Based on the geology of the area, its present density of development, the lack of long-term (3 to 4 years) monthly water level measurements, future development in the Whitmore unit, where ground water is concerned, should proceed very cautiously.

GLOSSARY

AA--A rough, broken, blocky crust formed as lava becomes hardened while being pushed by still-fluid lava behind it.

Acre-foot--The volume of water required to cover one acre to a depth of one foot: 43,560 cubic feet or 325,851 U.S. gallons. Commonly used in measuring volumes of water or reservoir storage space.

Alluvial Fan Deposit--A cone-shaped deposit of alluvium left by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountain canyons onto the lowland.

Alluvium--A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water.

Anticline--A fold, the core of which contains the stratigraphically older rocks; it is convex upward.

Aquifer--A geologic formation, group of formations or part of a formation that is water bearing and transmits water in sufficient quantity to supply springs and pumping wells.

Artesian Well--A well deriving its water from an artesian or confined water body. The water level in an artesian well stands above the top of the artesian water body it taps. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.

Breccia--A rock consisting of sharp fragments embedded in a fine-grained matrix, as sand or clay.

Confined Ground Water--Ground water under pressure whose upper surface is the bottom of an impermeable bed or a bed of distinctly lower permeability than the material in which the confined water occurs. Confined ground water moves under the control of the difference in head between the intake and discharge areas of the water body.

Confining Bed--A body of impermeable or distinctly less permable material stratigraphically adjacent to one or more aquifers.

Connate Water--Water trapped in the interstices of sedimentary rock at the time the rock was deposited. These waters may be fresh, brackish, or saline.

Contact--A plane or irregular surface between two different types or ages of rocks.

Effluent Stream--A stream or reach of a stream whose flow is being increased by inflow of ground water.

Electrical Conductivity (EC)--The measure of the ability of water to conduct an electrical current the magnitude of which depends on the concentration of minerals on the water. Related to total dissolved solids.

Evapotranspiration (ET)--That portion of rainfall or water applied to plants that is returned to the air through direct evaporation or by transpiration of plants.

Fault--A fracture, or fracture zone, along which has been displacement of the earth on one or both sides. This displacement may be a few centimetres or many kilometres. A Normal Fault is one in which the hanging wall appears to have moved downward relative to the footwall. Block Faulting is a type of normal faulting in which the crust is divided into structural blocks of different elevations and orientations.

Forebay--The recharge area of a confined aquifer.

Friable--Rock or soil that crumbles naturally or is easily broken, pulverized, or reduced to powder.

Geohydrology--A science that deals with the character, source, and made of occurrence of underground water.

Geomorphic Province--An area or region with similar land forms and a common geologic history.

Ground Water--(a) That part of the subsurface water that is in the zone of saturation; (b) loosely, all subsurface water as distinct from surface water.

Ground Water Basin--(a) A subsurface structure having the character of a basin with respect to the collection, retention, and outflow of water. (b) An aquifer or system of aquifers, whether or not basin shaped, that has reasonably well defined boundaries and more or less definite areas of recharge and discharge.

Head--(a) The pressure of a fluid on a given area at a given point caused by the height of the fluid surface above the point; (b) Water-level elevation in a well, or elevation to which the water of a flowing artesian well will rise in a pipe extended high enough to stop the flow.

Hydraulic Gradient--The change in static head per unit of distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head.

Hydrograph--A graph showing the changes in the water level in a well with respect to time.

Hydrologic Balance--An accounting of the inflow to, outflow from, and storage in a hydrologic unit; the relationship between evaporation, precipitation, runoff, and the change in storage, expressed by the hydrologic equation.

Hydrology--A science dealing with the origin, distribution, and circulation of water through precipitation, streamflow, infiltration, groundwater storage, and evaporation.

Impermeable--Not permitting the passage of water; impervious.

Infiltration--The flow or movement of water through the soil surface into the ground.

Lens--An underground deposit bounded by converging surfaces (at least one of which is curved), thick in the middle and thinning out towards the edges, resembling a convex lens.

Orogeny--A period of mountain-building that extends in time for some tens of millions of years.

Overdraft--The condition of a ground water basin where the amount of water withdrawn exceeds the amount of water replenishing the basin over a period of time.

Pahoehoe--A lava surface formed from very liquid lava which solidifies as ropy-looking coils.

Percolation--The slow passage of water through the earth to the ground water table. Once past the root zone this downward-moving water is considered Deep Percolation.

Permeability--The ability of a geologic material to transmit fluids. The degree of permeability depends on the size and shape of the pore space and the extent, size, and shape of their interconnections.

Porosity--Voids or open spaces in alluvium and rocks that can be filled with water. Primary Porosity is the pore space that was present at the time of deposition, Secondary Porosity is that which developed subsequent to deposition.

Potentiometric Surface--The surface to which the water in a confined aquifer will rise.

Pumpage--(a) The quantity of ground water pumped.

Pyroclastic--A general term for deposits composed of materials fragmented by volcanic explosion.

Recharge--Replenishment of ground water by infiltration of water from rainfall, streams, and other sources. Natural Recharge occurs without human intervention.

Sand--A term which denotes either (1) particles with diameter ranging from 1/16 to 2 mm or a sediment composed primarily of these particles.

Silt--A term which denotes either (1) particles with diameter ranging from 1/256 to 1/16 mm or (2) a sediment composed primarily of these particles.

Specific Capacity--The rate of discharge of a water well per unit of drawdown commonly expressed in gallons per minute per foot.

Specific Yield--The quantity of water that a unit volume of permeable rock or soil, after being saturated, will yield when drained by gravity. It may be expressed as a ratio or as a percentage by volume.

Spring--A place where ground water flows naturally from rock or soil onto the land surface or into a body of surface water. Its occurrence depends on the nature and relationship of rocks, permeable strata, the position of the water table, and topography.

Storage Capacity--The volume of space below the land surface that can be used to store ground water.

Subsurface Inflow--Ground water movement through the subsurface into a ground water basin.

Subsurface Outflow--Ground water movement through the subsurface out of a ground water basin.

Sustained Yield--The volume of ground water that can be extracted annually from a ground water basin without causing adverse effects.

Syncline--A fold, the core of which contains the stratigraphically younger rocks; it is concave upward.

Total Dissolved Solids (TDS)--The total quantity of minerals in solution in water, expressed in milligrams per litre.

Transmissivity--The rate at which ground water will flow through a unit width of the aquifer.

Tuff--A compacted pyroclastic deposit of volcanic ash and dust that may contain up to 50 percent sediments such as sand or clay.

Unconfined Ground Water--Ground water that has a free table; i.e., water not confined under pressure beneath relatively impermeable rocks.

Unconsolidated Material--(a) A sediment that is loosely arranged or unstratified, or whose particles are not cemented together; (b) Soil material that is in a loosely aggregated form.

Vadose Zone--A subsurface zone containing water under pressure less than that of the atmosphere. Zone of aeration.

Vesicular--The texture of a rock, esp. a lava, characterized by abundant cavities formed as a result of the expansion of gases during the fluid stage of the rock.

Volcanic Landforms--A Plug is a vertical, piplike body of magma that represents the conduit of a former volcanic vent. A Cone is a conical hill of lava and/or pyroclastics that is built up around a volcanic vent. A Pressure Ridge is an elongate uplift of the congealing crust of a lava flow.

Water-Bearing--The capability of yielding ground water of potable quality adequate for most beneficial purposes.

Water Table--That upper surface of an uncontined body; the level at which water stands in wells.

Well Log--A record made by the driller of a water well that lists underground materials encountered during drilling and information on the construction of the well (such as casing perforations and sanitary seal).

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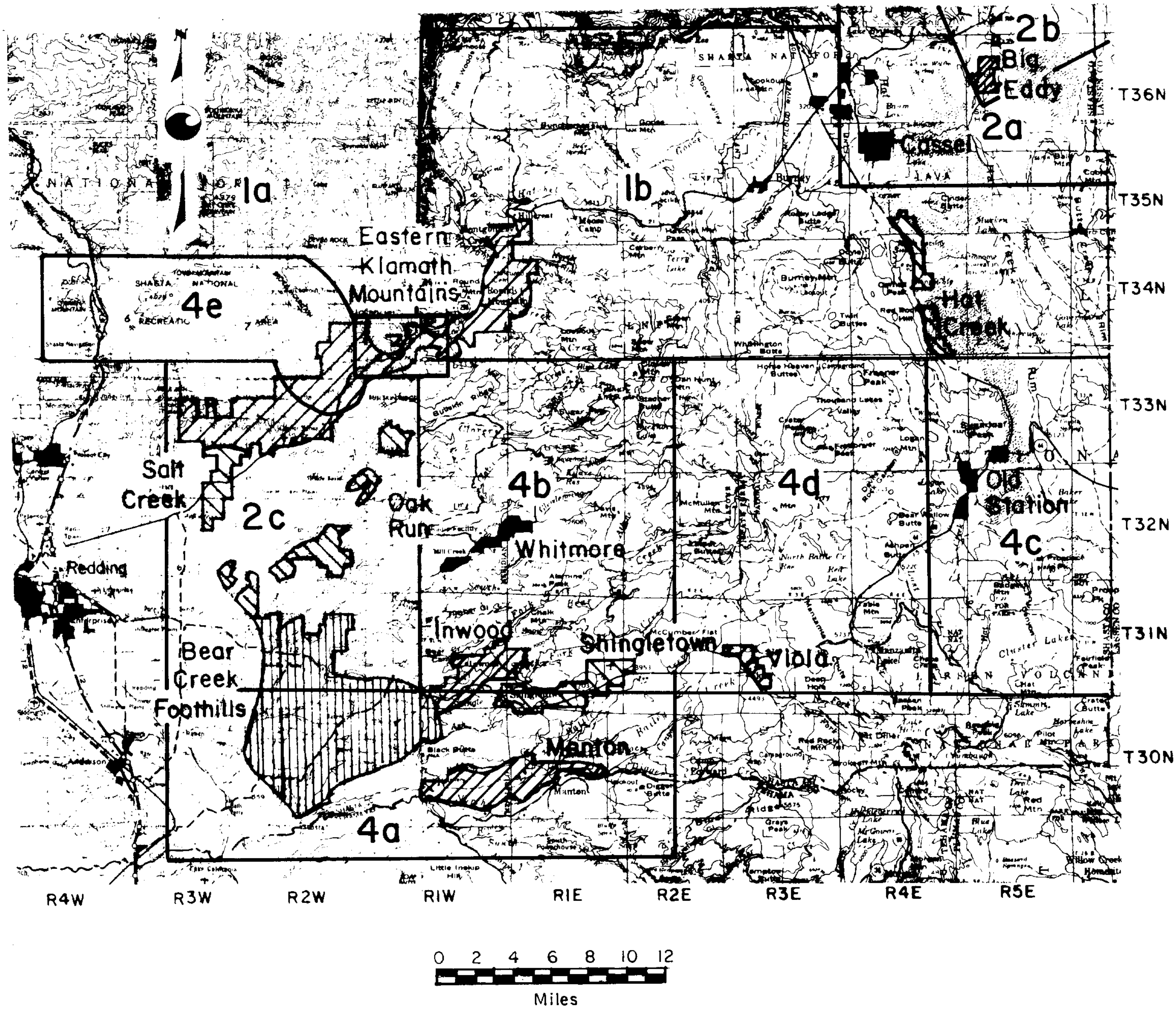


Eastern Shasta County Ground Water Study

Index to Geologic Mapping

1984

APPENDIX A

AGREEMENT BETWEEN SHASTA COUNTY WATER AGENCY AND THE STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES FOR A COOPERATIVE GROUND WATER STUDY IN SHASTA COUNTY

AGREEMENT BETWEEN SHASTA COUNTY WATER AGENCY

AND

THE STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES

FOR A COOPERATIVE GROUNDWATER STUDY IN SHASTA COUNTY

1. The Department of Water Resources, Northern District (State), agrees to conduct a two-year investigation of the groundwater resources in certain areas of Shasta County that are generally delineated on Figure 1, but which will be more specifically shown as the RA and RB land use designations in the Shasta County General Plan. The project will include studies on surface and subsurface geology and groundwater hydrology and will result in a formal report on said investigations to Shasta County Water Agency (Agency). The scope of work will be both at a reconnaissance level and detailed where data permits. Specific tasks to be performed by the State for the term of this contract will include the following:

A. Well inventory and water level measurements:
   1. Field locate wells and compile data;
   2. Determine groundwater depths and elevations at monthly intervals; prepare elevation and depth contour maps where sufficient wells are available;
   3. Determine general direction of groundwater movement where possible;
   4. Install and maintain continuous water level recorders on selected wells;
   5. Determine response of water level changes in wells to precipitation occurence;

B. Prepare isohyetal map (lines of equal precipitation) for entire study area;
   1. Estimate evapotranspiration and deep percolation in the various areas;
   2. Determine sources of groundwater recharge (streams and/or precipitation) and relative magnitude for the various areas;

C. Prepare maps of geologic formations on 15' quadrangles:
   1. Develop hydrogeologic cross-sections showing subsurface conditions relative to groundwater occurence;
   2. Identify water-bearing units and their recharge areas;
   3. Determine where barriers to groundwater movement occur;

D. Estimate groundwater availability:
   1. Determine existing well yields for different rock types and areas where wells exist;
   2. Estimate groundwater development potential for different rock types and areas shown on Figure 1;

E. Investigate pertinent water quality problems;

F. Provide a progress report of the first year's study by June 30, 1983;

G. Provide a final report which will include basic data, maps, cross-sections, findings, conclusions, and recommendations by June 30, 1984.

. During the term of this agreement, the Agency agrees to provide the State $30,000 toward the cost of this study and approximately $10,000 in in-kind services. Said services shall include, but not be limited to:

1. Monthly well measurements
2. Water Sampling
3. Servicing Water Level Recorders
4. Representing the County at meetings (cost of services may include travel expenses and overhead)

3. The term of this agreement shall be for the study period of August 1, 1982 through June 30, 1984.

4. The State will bill the Agency for $3,750 at the end of each fiscal quarter during the study period. Bills will be submitted in triplicate to the Shasta County Water Agency, 1855 Placer Street, Redding, CA, Attention: Larry Preston, Chief Engineer. The bills will itemize the costs incurred by the State for this study.

5. If sufficient funds are not made available by either the State or Shasta County for the second year of the study, Fiscal Year 1983-84, this contract is invalid or subject to renegotiation.

6. Executed on 20th day of July, 1982 by County at Redding, Shasta County, California and on ________ day of __________, 1982 by State at Red Bluff, Tehama County, California.

COUNTY OF SHASTA JUL 20 1982

D Maddox JUL 20 1982

Don Maddox, Vice-Chairman
Board of Supervisors, County of Shasta, State of California

ATTEST:

Richard C. Brennan

RICHARD C. BRENNAN, County Clerk and Ex officio Clerk of the Board of Supervisors, County of Shasta, State of California

Donald E. Owen

Philip P. Lorens

for ALBERT J. DOLCINI, Chief
Department of Water Resources
Northern District, State of California

Approved as to legal form and sufficiency:

John A. ...

Asst. Chief Counsel, DWR

APPROVED:

JOHN S. KENNY, County Counsel

BILL G. MINTON, County Executive

EDWARD B. DAVIS, Auditor-Controller

APPROVED

Jennifer Richardson

Department of Finance

FORM	POLICY	BUDGET

Department of General Services

APPROVED

SEP 15 1982

BY C.O. Thrush

Asst. Chief Counsel

APPENDIX B

GROUND WATER RECHARGE FROM PRECIPITATION FOR SELECTED EASTERN SHASTA COUNTY SITES

GROUND WATER RECHARGE POTENTIAL FROM PRECIPITATION
FOR SELECTED EASTERN SHASTA COUNTY SITES

Introduction

Ground water recharge potential from precipitation was estimated by the water budget method for nine study areas in eastern Shasta County. Shown in Figure 1, the study area locations are: two in the vicinity of Highway 299 East, near Bella Vista (#50), and Ingot (#38); three in the vicinity of Oak Run Road between Millville and Oak Run (#64, #51 and #39); and one at Whitmore (#53). In the vicinity of Highway 44, one is east of Inwood (#94) and another is east of Shingletown (#95). One is in the vicinity of the Volta Powerhouse (#125).

Study areas were generally about two to four square miles in size. In most cases, the study area was a small part of a much larger area of interest to Northern District geologists. Physical conditions such as vegetation, soil, precipitation, evapotranspiration, and percolation were averaged for each study area.

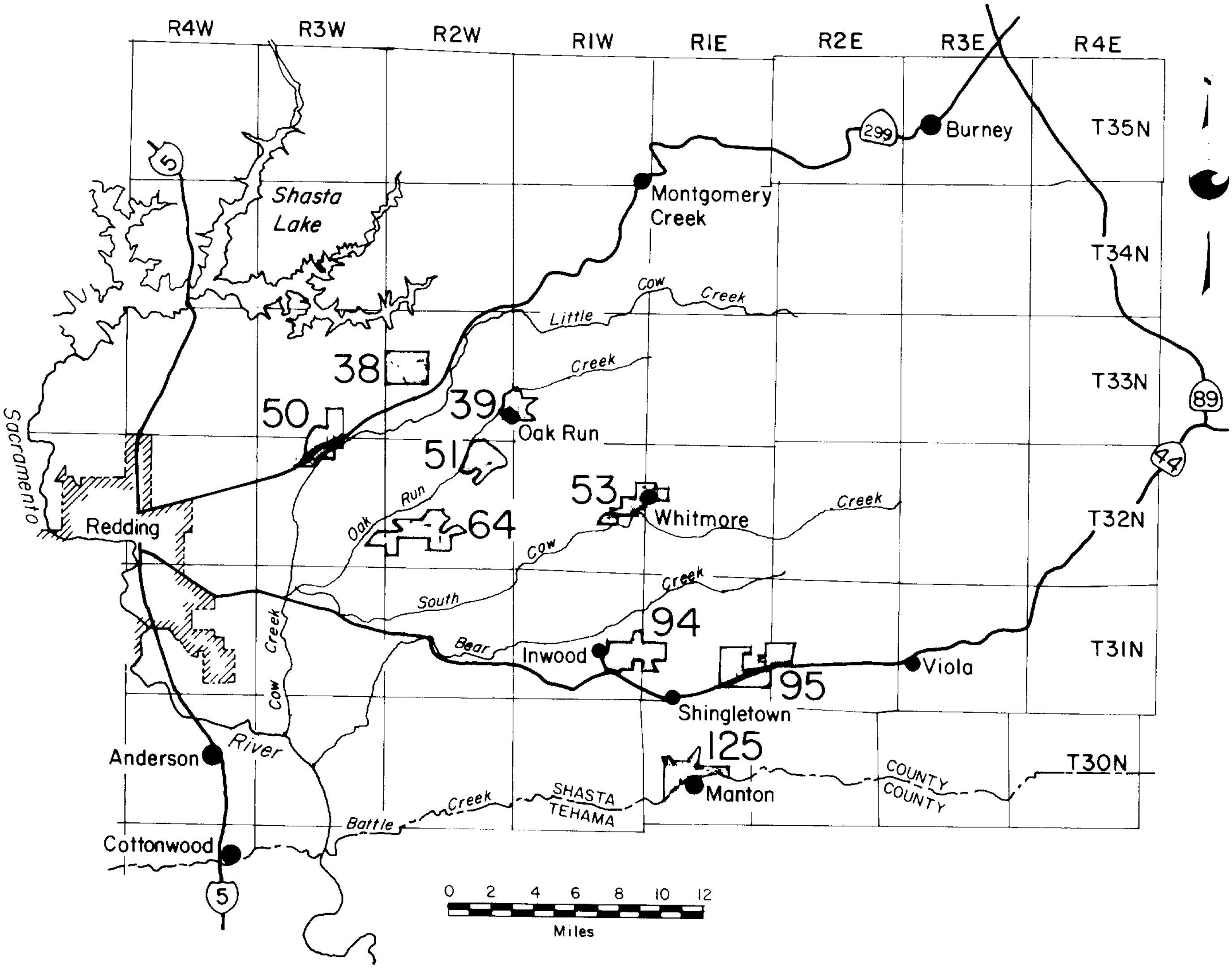
Study area elevations range from 600 feet (msl) to 3,800 feet. Mean annual pan evaporation rates range from 66 inches at the 600-foot elevation to 53 inches at the 3,800-foot elevation. Mean annual precipitation rates vary from 30 to 44 inches.

Water Budget Data

Inputs to a water budget include precipitation, evapotranspiration, soil depth, water-holding capacity, infiltration and percolation rates and steepness of slope (see sample computation, Table 1). Changes in vegetative cover must also be known; for example, growth stages of grasses and typical dates of desiccation, leaf-out and leaf drop for deciduous trees and changes in percent ground cover).

Precipitation

Isohyetal maps were used to estimate mean annual precipitation over each study area. Mean annual precipitation figures of 30, 34, 36, 38, 40, 42, and 44 inches were prorated into mean monthly amounts using monthly percent of annual rates for 105 years of record at Red Bluff. Red Bluff precipitation data were also used to compute minimum and maximum precipitation for



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT

Eastern Shasta County Ground Water Study

Ground Water Recharge Potential Sites

TABLE 1

WATER BUDGET CALCULATIONS FOR FORESTED DEEP SOILS IN STUDY AREA #94

In Inches

Month	Potential Evapo-transpiration, Trees & Brush	Mean Precipi-tation	Evapo-transpiration of Precipitation	Soil Moisture: Gain (+) Loss (-)	Soil Moisture: 10.0" Maximum Content	Total Evapo-transpiration	Deep Perco-lation	Surface Runoff
Oct.	2.0	2.0	2.0	0	0	2.0	0	0
Nov.	1.0	5.3	1.0	+3.3	3.3	1.0	0	1.0
Dec.	.7	6.7	.7	+4.0	7.3	.7	0	2.0
Jan.	.7	7.7	.7	+2.7	10.0	.7	.3	4.0
Feb.	1.0	5.5	1.0	0	10.0	1.0	2.5	2.0
Mar.	1.7	4.3	1.7	0	10.0	1.7	1.6	1.0
Apr.	2.5	3.1	2.5	0	10.0	2.5	.6	0
May	3.6	1.7	1.7	-1.9	8.1	3.6	0	0
Jun.	4.4	.8	.8	-3.6	4.5	4.4	0	0
Jul.	4.5	.1	.1	-2.3	2.2	2.4	0	0
Aug.	3.8	.3	.3	-1.1	1.1	1.4	0	0
Sep.	3.1	.5	.5	-1.1	0	1.6	0	0
	29.0	38.0	13.0		10.0	23.0	5.0	10.0

each study area. For example, absolute maximum annual precipitation at Red Bluff was 193 percent of the mean and absolute minimum annual precipitation was 44 percent of the mean. These percentages were applied to each mean annual precipitation zone to estimate maximum and minimum amounts of precipitation.

Evapotranspiration

Pan evaporation data were used to estimate evapotranspiration by grass, brush, and trees. Estimates of annual pan evaporation were made for each study area. Annual pan evaporation rates were estimated by interpolation of data from pan stations located outside the study area at Fall River Valley in eastern Shasta County and at Gerber in Tehama County. Monthly percent of annual pan evaporation was calculated using the 25-year record from Gerber 1SW for the period 1959-1983. Mean monthly pan evaporation was calculated for the 53-, 60-, 62-, 64-, and 66-inch mean annual zones.

Vegetation

Vegetation type and density of cover were determined for each study site. Vegetation is important because of rooting depth and therefore depth of soil moisture extraction, evapotranspiration rate, and interception of precipitation.

Infiltration of water is encouraged by a dense canopy of brush and trees that intercepts and adsorbs raindrop impact, thereby helping to preserve soil structure. Also, organic litter tends to accumulate more under perennial vegetation and encourages infiltration.

Soils

Soil types within the study areas were determined from the publication "Soil Survey of Shasta County Area, California", August 1974, by U. S. Department of Agriculture, Soil Conservation Service and Forest Service. This report contained information about soil depth to relatively impervious material, soil water-holding capacity, and infiltration/runoff/percolation characteristics of the soil to a depth of five feet.

Topography

Generally, the steeper the ground slope the greater the rate of runoff.

Computation Procedure

An annual water budget was computed for each study site on a month-by-month basis, beginning with October of each year. The monthly budget for study site #94 is shown in Table 1. Precipitation was distributed into estimated amounts of runoff, infiltration, soil moisture extraction (evapotranspiration), soil storage or deep percolation beyond plant roots. To make these estimates, consideration must be given to precipitation, slope, changes in vegetative ground cover, availability of storage space for additional water within the soil, changes in infiltration rate (this changes with duration of rainfall), soil structure, and texture.

As shown in Table 2, soil profile material at the five-foot depth consists, in most cases, of relatively impervious rock such as sandstone, tuff, or shale. In a few instances where soils were deeper than five feet (soil survey information stops at five feet), clay or loam was present; it was assumed that relatively impervious materials lay not too far below the clay and loam (perhaps within a depth of about three more feet).

Water budget calculations were run for mean, maximum, and minimum precipitation amounts for major vegetative groupings of trees-brush and grass. Separate calculations for these two vegetative groupings were necessary because of significant differences in rooting depth, rate of evapotranspiration, ground cover, and effect upon infiltration rate.

Potential recharge was determined separately for tree-brush lands and grasslands for each study site, if both types existed in significant amount. Some sites had only tree-brush vegetation.

Findings

The percolation of precipitation to ground water is dependent upon the existence of free water, as in the case of a saturated soil overlying bedrock materials or water flowing within a stream channel 24 hours a day, 12 months a year. Analysis of the monthly water budget computations for each study site indicates that water within the soil first becomes available for ground water recharge in December in wet years and in January in average precipitation years; free water within the soil is never available for recharge during dry years. Recharge potential continues through April in wet years and through March in average years.

TABLE 2

STUDY SITE LOCATIONS AND SOILS

1/ Number	Distance and Direction from Nearest Community	Township, Range and Section Number	Elevation (Ft)	Pan Evaporation Zone (In)	Soils			
					Series Name and Percent Slope	Depth (In)	Maximum Available Moisture (In)	Areal % of Study Area
38	Ingot 3W	T33N/R2W/Sec. 17-20	1,600	62	Boomer, 15-50%	40-60	10	35
					Neuns, 8-50%	20-40	4	16
					Auburn, 8-50%	15-32	6	15
					Diamond Springs, 8-30%	24-60	7	7
39	Oak Run	T33N/R1W/Sec. 3 and R2W/Sec. 25	1,500	62	Aiken, 0-15%	> 60	9	55
					Guenoc, 0-30%	20-40	6	25
					Los Robles, 0-3%	> 60	11	15
					Toomes, 0-30%	4-20	2	15
50	Bella Vista 3NE	T32N/R3W/Sec. 3 & 4 and Sec. 34	600	66	Tehama, 0-8%	48-60	12	12
					(Cobbly Alluvial Land)	4-24	3	11
					Gaviota, 0-50%	10-18	2	11
					Sehorn, 8-30%	16-28	5	11
51	Oak Run 3SW	T32N/R2W/Sec. 2	1,000	64	Sehorn, 30-50%	28-40	6	44
					Toomes, 0-30%	4-20	1	34
					Kilark, 30-50%	24-45	6	10
					Pentz-Supan, 50-70%	6-20	2	10
53	Whitmore	T32N/R1W/Sec. 13	2,200	44	Akin, 0-15%	> 60	10	87
					Guenoc, 0-30%	40	6	4
					Shingletown, 0-8%	40-60	12	4
					Cohasset, 0-30%	> 60	12	2
64	Millville 5NE	T32N/R2W/Sec. 19-21 and Sec. 27-30	800	65	Toomes, 0-50%	4-20	2	35
					Newtown, 0-50%	> 60	11	27
					Pentz-Supan, 50-70%	6-20	2	15
					Kilark, 10-50%	25-45	8	7

1/ Study site number based upon page number of study site location in publication: "Soil Survey of Shasta County Area, California," August 1974, USDA, Soil Conservation Service and Forest Service.

TABLE 2 (Continued)

1/ Number	Distance and Direction from Nearest Community	Township, Range and Section Number	Elevation (Ft.)	Pan Evaporation Zone (In.)	Soils			
					Series Name and Percent Slope	Depth (In.)	Maximum Available Moisture (In.)	Areal % of Study Area
94	Inwood 1SE (Deep Soil Areas)	T31N/R1W/Sec. 26	2,200	58	Aiken, 0-50%	> 60	10	95
					Cohasset, 0-50%	> 60	12	2
94	Inwood 2E (Shallow Soil Areas)	T31N/R1W/Sec. 24	2,200	58	Windy & McCarthy 0-75%	40-60	7	20
					Cohasset, 0-70%	> 60	12	15
					Supan, 30-50%	24-40	7	15
					Kilarc, 30-50%	25-45	8	10
95	Shingletown 4NE	T31N/R1E/Sec. 25-26	3,800	53	Windy & McCarthy, 0-30%	40-60	7	80
					Cohasset, 0-30%	> 60	10	20
125	Manton	T30N/R1E/Sec. 16-17 and Sec. 20-22	2,000	60	Guenoc, 0-30%	20-30	4	30
					Cohasset, 0-30%	48-60	9	25
					Aiken, 0-15%	> 60	9	18
					Toomes, 0-50%	4-15	2	14

1/ Study site number based upon page number of study site location in publication: "Soil Survey of Shasta County Area, California," August 1974, USDA, Soil Conservation Service and Forest Service.

The amount of water available for ground water recharge for each study site shown in Table 2 is approximate because some water will move laterally along the top of bedrock and reappear as a spring.

Site #94 (Inwood 2E and 1SE) was the only site separated into generally shallow and deep soil areas. This separation resulted in significant differences of estimated percolation because of significant differences in steepness of slope, vegetative cover, and soil depth. The deep soil areas appear to have a greater potential for infiltration because they tend to be less steep. They are densely forested, too, so they apparently can infiltrate and percolate about four times more water than the shallow, relatively steep soil areas.

Site #94 also had about one percent of its total area irrigated by water diverted from local streams. Due to the small size of the irrigated area and the probable relative impermeability of the underlying bedrock, it is believed that flood irrigation water spread over the ground surface from May through September would contribute little to ground water.

The Oak Run study site #39 also had surface irrigation from local streamflow. Irrigated land amounts to about 10 percent of the total study area. In this instance, it was assumed that irrigation water provided significant recharge potential. These amounts are shown in Table 3.

Calculations using minimum precipitation resulted in ground water recharge potential that was essentially non-existent for all study sites. As would be expected, maximum precipitation produces maximum recharge potential.

TABLE 3

SUMMARY OF ANNUAL GROUND WATER RECHARGE POTENTIAL
FROM AVERAGE, WET AND DRY YEAR PRECIPITATION

In Inches

Study Site Number	Vegetation Type	Precip-itation	Evapotrans-piration	Runoff	Percolation Below Five Feet
38	Trees-Brush	40	20	17	3
		77	22	38	17
		18	14	4	Nil
39	Trees-Brush	44	24	17	3
		85	27	44	14
		19	17	2	Nil
	Grasslands	44	23	21	Nil
		85	29	50	6
		19	14	5	Nil
	Irrigated Land	44	23	21	Nil/7 a/
		85	29	50	6/6 a/
		19	14	5	Nil/8 a/
50	Brushlands	34	15	17	2
		66	17	47	2
		15	11	4	Nil
	Grasslands	34	19	14	1
		66	24	34	8
		15	13	2	Nil
	Woodlands	34	24	6	4
		66	27	19	20
		15	14	1	Nil
51	Trees-Brush	40	18	17	5
		77	22	45	10
		18	14	4	Nil
	Grasslands	40	21	16	3
		77	25	46	6
		18	13	5	Nil
53	Trees-Brush	44	23	12	9
		85	26	20	39
		19	18	1	Nil

a/ Percolation by irrigation water that covers about 10 percent of the study site.

TABLE 3 (Continued)

Study Site Number	Vegetation Type	Precip-itation	Evapotrans-piration	Runoff	Percolation Below Five Feet
64	Trees-Brush	36	18	17	1
		69	22	38	9
		16	15	1	Nil
	Grasslands	36	21	14	1
		69	23	37	9
		16	15	1	Nil
94 (Deep Soil)					
	Trees-Brush	38	23	10	5
		73	25	30	18
		17	15	2	Nil
94 (Shallow Soil)					
	Trees-Brush	38	20	17	1
		73	21	48	4
		17	13	4	Nil
95	Trees-Brush	40	21	8	11
		77	24	29	24
		18	18	Nil	Nil
125	Trees-Brush	30	18	8	4
		58	21	27	10
		13	13	Nil	Nil
	Grasslands	30	17	11	2
		58	20	33	5
		13	12	1	Nil